

For Reference

NOT TO BE TAKEN FROM THIS ROOM

Ex LIBRIS
UNIVERSITATIS
ALBERTAENSIS





Digitized by the Internet Archive
in 2023 with funding from
University of Alberta Library

<https://archive.org/details/Sharma1972>

THE UNIVERSITY OF ALBERTA

RADIATION DOSE DISTRIBUTIONS AROUND RADIOACTIVE
SOURCES AND THEIR PERTURBATION BY ABSORBING MATERIALS

by



PURUSHOTTAM DASS SHARMA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF PHYSICS

EDMONTON, ALBERTA

FALL, 1972

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled RADIATION DOSE DISTRIBUTIONS AROUND RADIOACTIVE SOURCES AND THEIR PERTURBATION BY ABSORBING MATERIALS, submitted by PURUSHOTTAM DASS SHARMA, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

Radiation dose distribution measurements were carried out with caesium-137 and cobalt-60 radioactive sources. Studies were made for the attenuation of a beam of finite cross-section by different absorbing materials placed between the source and the detector. The absorbing materials studied were lead, iron and water. The attenuation curves with a thickness of up to four mean free paths of absorber were obtained experimentally and the buildup factors derived, for both ^{137}Cs and ^{60}Co radiations. The experimental buildup factors were compared with the available theoretical data. Radiation distribution measurements were made around ^{137}Cs line sources and for different sized and shaped applicators. The radiation distribution around these radioactive sources and the experimental buildup factors for different absorbing materials were useful in calculating the dose rate at the points of interest. Thermoluminescence LiF-7 powder was studied and used for these measurements.

ACKNOWLEDGEMENTS

I wish to thank the following people who have been very helpful and cooperative in completion of this project: My supervisor, Dr. S.R. Usiskin, for suggesting this project. His comments and guidance in the development of this work is most appreciated. I am also indebted to Dr. J.W. Scrimger for much valuable discussion and his involvement in both performing the experiments and writing up this work. Thanks also to Lorenz Stenger, Tom Drennen and the rest of the technical staff at Dr. W.W. Cross Cancer Institute.

I reserve my deepest gratitude to my wife, Kusum, who has encouraged and supported me during many difficult times. Completion of this work is due to her constant encouragement. I wish to express my thanks to Mr. K. Liesner for the preparation of the illustrations on such a short notice and to Mrs. Mary Yiu for typing the final draft of the thesis.

I wish to express my appreciation to the Radiotherapy Department of Dr. W.W. Cross Cancer Institute for the use of radiation sources. Finally I thank both the University of Alberta and the Dr. W.W. Cross Cancer Institute for their financial assistance during the course of this project.

TABLE OF CONTENTS

	<u>Page</u>
CHAPTER 1 : INTRODUCTION	1
CHAPTER 2 : THEORY OF PENETRATION AND DIFFUSION OF GAMMA RAYS	4
2.1 Narrow Beam and Broad Beam Attenuation	4
2.2 The Transport Equation	7
2.3 Approximate Solution of the Transport Equation	11
2.4 Analytical Approximation for Buildup Factors	13
CHAPTER 3 : EXPERIMENTAL ARRANGEMENTS	15
3.1 Teletherapy Sources	15
3.2 Thermoluminescence Dosimeter	17
3.2.1 Mechanism of Thermoluminescence	17
3.2.2 Characteristics of LiF-7 Powder	20
3.3 Setup for the Buildup Measurements	27
3.4 ^{137}Cs Sealed Sources and the Cervix Applicators	31
3.5 Radiation Distribution Measurements around Cervix Applicators	33
CHAPTER 4 : EXPERIMENTAL RESULTS	37
4.1 Buildup Factors for ^{137}Cs and ^{60}Co Radiations	39
4.2 Radiation Distribution around ^{137}Cs Line Sources	47

	<u>Page</u>
CHAPTER 5 : CLINICAL IMPLICATIONS	55
5.1 Interstitial and Intracavitary Radiotherapy	55
5.2 Point Source Approximation used in the Estimation of Dose Rate at the Points of Interest	59
5.3 External Beam Shield used in Treatment with Teletherapy Units	62
5.4 Usefulness of the Buildup Data for the Assessment of Shield Thickness	63
CHAPTER 6 : CONCLUSIONS	65
6.1 Results and Discussion on Buildup Factors	65
6.2 Radiation Distribution Results and Discussion	66
REFERENCES	68
APPENDIX A APL program for point source approximation	72

LIST OF TABLES

	<u>Page</u>
1. Buildup factor ratio	38
2. Comparison of experimental and theoretical values for a single 21.5 mg Ra eq ^{137}Cs line source	67

LIST OF ILLUSTRATIONS

1. Narrow beam and broad beam attenuation	5
2. Infinitesimal cylinder used in Transport Equation	8
3. Caesium-137 "Cs-600" unit	16
4. "Theratron 80" Cobalt-60 unit	16
5. Source Capsule	18
6. Thermally stimulated phosphorescence	18
7. Block diagram of TLD reader	22
8. Linear response of group C thermoluminescent powder	25
9. Quality dependence of group A thermoluminescent powder	26
10. Fading of the group B thermoluminescent powder	28
11. Experimental arrangements with ^{137}Cs unit	30
12. Experimental arrangements with ^{60}Co unit	32
13. Intrauterine tube	34
14. Vaginal applicator	34
15. Penetration of ^{137}Cs radiation in lead (A) Attenuation (B) Buildup factor	41
16. Penetration of ^{137}Cs radiation in iron (A) Attenuation (B) Buildup factor	42

17. Penetration of ^{137}Cs radiation in water (A) Attenuation (B) Buildup factor	43
18. Penetration of ^{60}Co radiation in lead (A) Attenuation (B) Buildup factor	44
19. Penetration of ^{60}Co radiation in iron (A) Attenuation (B) Buildup factor	45
20. Penetration of ^{60}Co radiation in water (A) Attenuation (B) Buildup factor	46
21. Penetration of ^{60}Co radiation in lead for different beam cross-section (A) Attenuation (B) Buildup factor	48
22. Isodose curves for a 60 mCi ^{137}Cs line source	50
23. Isodose curves for intrauterine tube loaded with two 30 mCi and one 45 mCi ^{137}Cs line sources	51
24. Isodose curves for vaginal applicator loaded with two 75 mCi ^{137}Cs line sources	52
25. Isodose curves for vaginal applicator with lead shield loaded with two 75 mCi ^{137}Cs line sources	53
26. Isodose curves for the combination of vaginal applicator and intrauterine tube	54
27. Anteroposterior radiograph	57
28. Lateral radiograph	58

CHAPTER 1

INTRODUCTION

Radiotherapeutic treatment of carcinoma of the cervix uteri is normally divided into two parts:

- (a) The intracavitary treatment
- (b) External therapy.

For intracavitary treatment the gamma radiation sources are loaded into different sized and shaped applicators and are inserted into body cavities (uterus and vagina). The vaginal sources may be shielded posteriorly by lead to reduce the rectal dose.

For external therapy a beam of particular cross-section is directed at the patient from an external source. During this treatment the area which has already received a tumour-lethal dose by intracavitary treatment is protected from over exposure by placing a specially shaped shield into the beam, while the rest of the area of interest is irradiated to a tumour-lethal dose.

When multiple sources are employed in intracavitary treatment, a variety of radiation dose distributions depending upon the strength and the geometrical distribution of the sources is possible. Further, the

distribution will differ if the sources are partially shielded to protect certain body organs from excessive exposure.

Studies were thus made to investigate the physical aspects of this radiotherapy treatment. Radiation distribution measurements for ^{137}Cs line sources with and without shield were made and isodose curves plotted. These isodose curves could be superimposed to determine the dose rate at a point of interest from a combination of line sources. It was also observed that the dose rate behind the shield from both ^{137}Cs line sources and external therapy sources was greater than the expected value as calculated by using standard attenuation data. This buildup in the dose rate was quite significant even at small thickness of the absorbing material.

Radiations of different qualities were used to study this buildup in more detail for different absorbing materials. Extensive studies, especially for reactor shielding design, have been done on the buildup factors for broad beams from point and plane parallel sources in an infinite absorbing material. There has been very little work⁽¹⁻³⁾ on the buildup factors for finite cross-section of the beam of gamma radiation and finite thickness of the absorbing material.

This work has thus been divided into two parts

a) The attenuation of gamma radiation by absorbing materials used both in external therapy and intracavitary treatment. b) The radiation distribution around ^{137}Cs line sources used in intracavitary treatment.

CHAPTER 2

THEORY OF PENETRATION AND DIFFUSION OF GAMMA RAYS

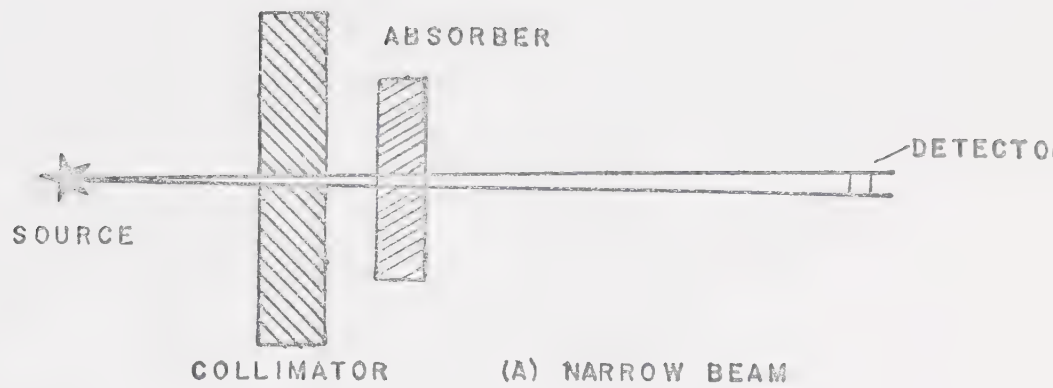
2.1 Narrow Beam and Broad Beam Attenuation

When an absorbing material is placed between a source of gamma radiation and a detector, the amount of radiation observed by the detector depends upon the thickness of the absorbing material and the amount of scattered radiation that reaches the detector. Thus, two limiting cases are visualized:

- a) when essentially no scattered radiation reaches the detector. This is termed "Narrow beam attenuation".
- b) when a maximum amount of the scattered radiation reaches the detector. This is termed "Broad beam attenuation".

These are shown diagrammatically in fig. 1.

For the narrow beam the only radiation that contributes to the intensity at the detector is essentially the primary radiation which has not undergone any interaction. The primary radiation which undergoes an interaction will either be absorbed or deflected from its path and does not reach the detector. Thus, the intensity of radiation reaching the detector is given by:



(B) BROAD BEAM

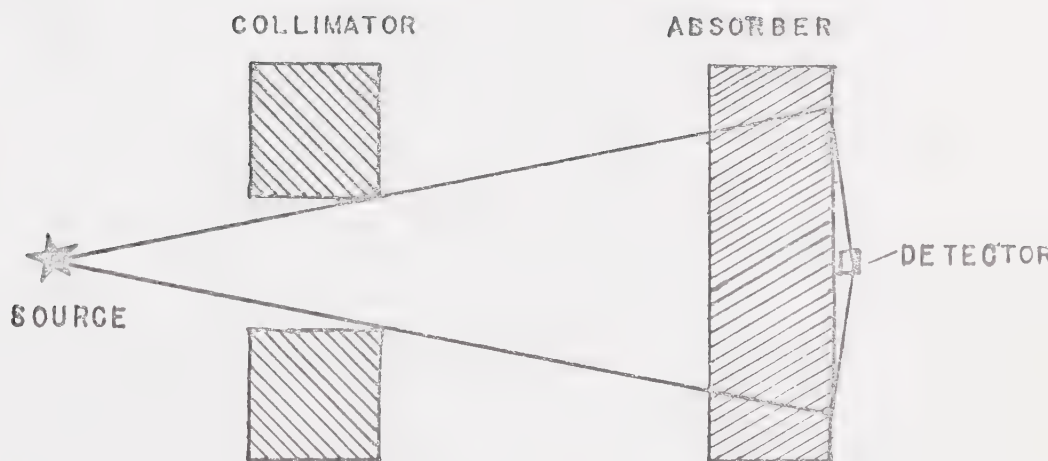


Fig.11

NARROW BEAM AND BROAD BEAM ATTENUATION

$$I = I_0 e^{-\mu x} \quad (1)$$

where

I is the measured intensity with material thickness of x cm.

I_0 is the measured intensity without any absorbing material between the source and the detector.

μ is the linear attenuation coefficient of the absorbing material (cm^{-1}).

In most practical problems, the experiment is closer to the broad beam situation, since the detector not only observes the primary radiation but also some portion of the scattered radiation. In this case the measured intensity is given by

$$I = B I_0 e^{-\mu x} \quad (2)$$

The factor B , "Buildup Factor", is introduced to correct for scattered radiation. Thus the buildup factor is defined as the ratio of the measured intensity due to the primary and scattered radiation reaching the detector to the measured intensity of the primary radiation at the detector, for a particular absorbing material and thickness, and for a particular photon energy.

2.2 The Transport Equation

The flow of gamma radiation, primary as well as scattered radiation, through matter is completely determined as the solution of the transport equation^(4,5). This equation describes the balance between the number of photons of given energy and direction entering and leaving an infinitesimal cylinder as shown in fig. 2. The balance may be formulated for conditions where the gamma radiation source is constant in time and, therefore, the flow of photons throughout the medium is constant.

Consider a point γ and an infinitesimal right cylinder with a base area A centered at γ and with a height h whose lateral surface is parallel to a direction Ω . Let us define the flux $I(\gamma, \Omega, \lambda) d\lambda d\Omega$ as the number of photons with wavelengths between λ and $\lambda + d\lambda$ and with direction between Ω and $\Omega + d\Omega$ which cross a unit area of the base of the infinitesimal cylinder per unit time. (The wavelength in Compton units $\lambda = m_0 c^2 / E$ is used to indicate the energy because this simplifies the treatment of the Compton effect).

The net number of photons with specified direction and energy leaving the cylinder per unit time is given by:

$$AI(\gamma + h\Omega, \Omega, \lambda) - AI(\gamma, \Omega, \lambda) \quad .$$

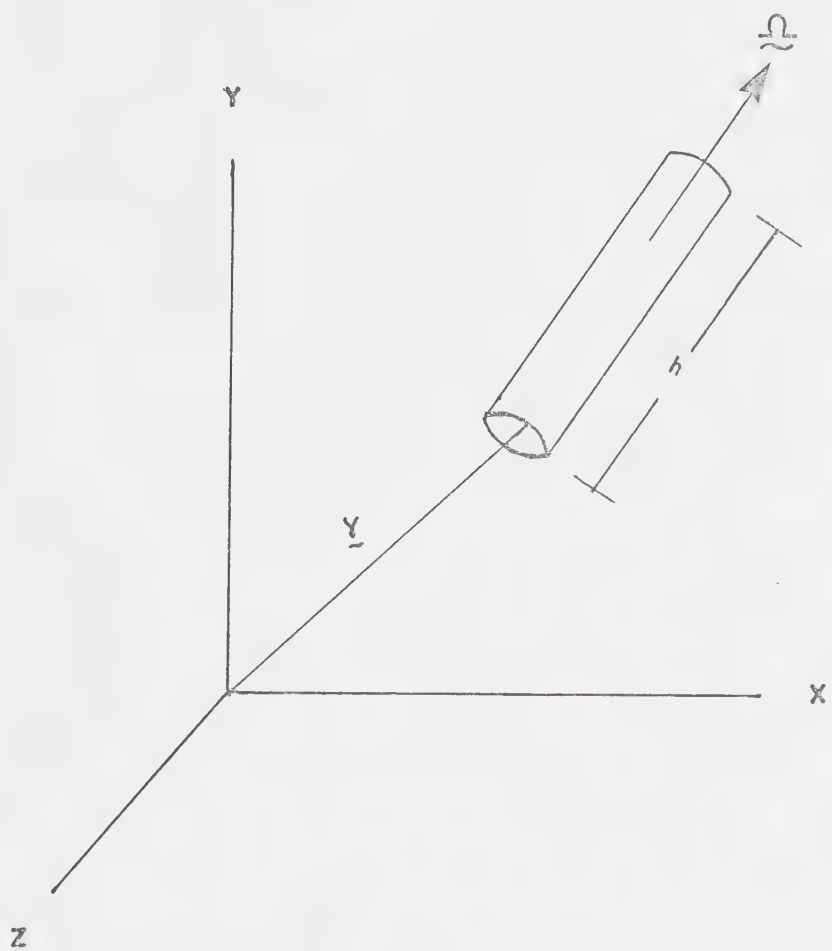


Fig.: 2

INFINITESIMAL CYLINDER USED
IN TRANSPORT EQUATION

In its differential form this will be

$$Ah \, \Omega \cdot \text{grad } I(\gamma, \Omega, \lambda) \quad . \quad (3)$$

There are three factors which contribute to this net outflow. One is the narrow beam attenuation in the whole volume of the cylinder amounting to $-\mu I(\gamma, \Omega, \lambda) hA$. The second is the scattering of photons of direction Ω' and energy $m_0 c^2 / \lambda'$ into the given direction and energy, Ω and $m_0 c^2 / \lambda$. This scattering if it happens anywhere within the cylinder volume Ah , contributes to a positive outflow from the cylinder. This depends upon the product of the flux $I(\gamma, \Omega', \lambda')$ and of the probability $k(\Omega' \rightarrow \Omega; \lambda' \rightarrow \lambda)$ of photon scattering into Ω and λ from Ω' and λ' , per unit path through the medium and per unit $d\Omega$ and $d\lambda$. The third contribution arises from the source, if any, of photons of the given energy and direction within the cylinder. If the photons are produced with a source density $S(\gamma, \Omega, \lambda)$ per unit volume, created per unit time at γ which move in the direction Ω per unit solid angle and per unit λ , then the corresponding excess flow out of the cylinder will be $AhS(\gamma, \Omega, \lambda)$.

The transport equation is obtained by equating (3) to the sum of three factors contributing to this. As each of these quantities is proportional to the volume Ah of the cylinder, the volume can be factored out. Then the equation is

$$\begin{aligned}
\tilde{\Omega} \cdot \text{grad } I(\tilde{\gamma}, \tilde{\Omega}, \lambda) &= -\mu I(\tilde{\gamma}, \tilde{\Omega}, \lambda) \\
&+ \int_0^\lambda d\lambda' \int_{4\pi} d\tilde{\Omega}' k(\tilde{\Omega}' \rightarrow \tilde{\Omega}; \lambda' \rightarrow \lambda) I(\tilde{\gamma}, \tilde{\Omega}', \lambda') \\
&+ S(\tilde{\gamma}, \tilde{\Omega}, \lambda) \quad . \quad (4)
\end{aligned}$$

This equation is in a quite general form. In most applications only Compton scattering has been included in the probability function k . This function is then simply equal to the Klein-Nishina cross-section $d_e \sigma / d\lambda' d\tilde{\Omega}'$ times the number of electrons per unit volume NZ , where N is the number of atoms per unit volume and Z is the number of electrons per atom. The Klein-Nishina cross-section is given by⁽⁴⁾

$$\begin{aligned}
\frac{d_e \sigma}{d\lambda' d\tilde{\Omega}'} &= \frac{1}{2} \left(\frac{e^2}{mc^2} \right)^2 \left(\frac{\lambda'}{\lambda} \right)^2 \left[\frac{\lambda}{\lambda'} + \frac{\lambda'}{\lambda} + (\lambda - \lambda')(\lambda - \lambda' - 2) \right] \times \\
&\times \delta(1 - \cos\phi + \lambda' - \lambda) \quad (5) \\
&= k(\lambda, \lambda') \delta(1 - \cos\phi + \lambda' - \lambda)
\end{aligned}$$

where

$$k(\lambda, \lambda') = \frac{1}{2} \left(\frac{e^2}{mc^2} \right)^2 \left(\frac{\lambda'}{\lambda} \right)^2 \left[\frac{\lambda}{\lambda'} + \frac{\lambda'}{\lambda} + (\lambda - \lambda')(\lambda - \lambda' - 2) \right]$$

and is the Klein-Nishina differential coefficient for Compton scattering with a wavelength change from $\lambda' \rightarrow \lambda$.

$$\delta(1 - \cos\phi + \lambda' - \lambda)$$

is the Dirac's delta function and represents the Compton

law of wavelength shift. As the angle of scattering ϕ is formed by $\tilde{\Omega}$ and $\tilde{\Omega}'$, therefore, $\cos \phi = \tilde{\Omega} \cdot \tilde{\Omega}'$.

Then

$$k(\tilde{\Omega}' \rightarrow \tilde{\Omega}; \lambda' \rightarrow \lambda) = k(\lambda, \lambda') \delta(1 - \tilde{\Omega} \cdot \tilde{\Omega}' + \lambda' - \lambda)NZ \quad (6)$$

and equation (4) can be written as

$$\begin{aligned} \tilde{\Omega} \cdot \text{grad } I(\gamma, \tilde{\Omega}, \lambda) &= -\mu I(\gamma, \tilde{\Omega}, \lambda) \\ &+ \int_0^\lambda d\lambda' \int_{4\pi} d\tilde{\Omega}' k(\lambda, \lambda') \delta(1 - \tilde{\Omega} \cdot \tilde{\Omega}' + \lambda' - \lambda)NZ \times \\ &\times I(\gamma, \tilde{\Omega}', \lambda') + S(\gamma, \tilde{\Omega}, \lambda) . \end{aligned} \quad (7)$$

This is the transport equation governing the transport of gamma radiation through matter. Because of its basic complexity, it is virtually never solved in closed form in practical cases. Its greatest value arises in estimating buildup factors that are applied to the calculations based on the narrow beam attenuation approximation.

2.3 Approximate Solution of the Transport Equation

Various techniques are employed to gain an approximate solution to this equation⁽⁶⁻¹⁴⁾.

The most widely used techniques are (a) Moments method,

(b) Method of successive scattering, (c) Monte Carlo method. A complete description of these techniques is not necessary since they are well developed elsewhere. All these techniques have their own limitations. The moments method^(6,7) yields results of high accuracy for field positions at an appreciable distance from the source - up to 20 mean free paths. A mean free path (m.f.p.) is defined as the thickness of the absorbing material required to reduce the intensity of gamma radiation by a factor e . Thus, for narrow beam attenuation one mean free path is equal to $1/\mu$ where μ is the linear attenuation coefficient of the absorber. The moments method technique can only be used for the infinite homogeneous absorbing medium, and does not provide a satisfactory description of the radiation field near the source i.e. a distance less than one m.f.p. The successive scattering method^(8,9) takes into account the finite absorbing material. This technique calculates successively the probability that a photon will be transmitted with zero, one, two and three scatterings and then sums to find the total probability of the transmission. This does not take into account back scattered photons important at low photon energies and thick absorbing material. The Monte Carlo⁽¹⁰⁻¹⁴⁾ technique is quite effective for moderate thicknesses

of the absorbing material. For thick absorbing materials the calculations become time consuming even with computers.

The maximum information is available from calculations by moments method. It covers the energy range from 0.5 MeV to 10 MeV, eight different infinite absorbing materials of varied atomic numbers and upto 20 m.f.p.

2.4 Analytical Approximation for Buildup Factor

Various analytical formulas⁽¹⁵⁾ have been developed to fit the point source buildup factors of moments method⁽⁶⁾. These formulas greatly reduce the tedious mathematical calculations. Some of the important analytical methods are:

(a) Berger's Formula

$$B(\mu x) = 1 + a \mu x e^{b \cdot \mu x} . \quad (8)$$

The values of the two parameters a and b have been obtained by Chilton⁽¹⁶⁾. Its accuracy up to 10 m.f.p. is claimed to be of the same order as that given by the moments method.

(b) Taylor's Formula⁽⁶⁾

$$B(\mu x) = \sum_{n=1}^N A_n e^{-\alpha_n \mu x} . \quad (9)$$

In practice only two exponential terms are required to fit the results of moments method within 5% over most of the range. Then

$$B(\mu x) = A_1 e^{-\alpha_1 \mu x} + A_2 e^{-\alpha_2 \mu x} \quad (10)$$

and

$$A_1 + A_2 = 1 .$$

(c) Capo's Formula

$$B(\mu x) = \sum_{i=0}^3 B_i (\mu x)^i \quad (11)$$

where

$$B_i = \sum_{j=0}^4 C_{ij} (1/E)^j .$$

The values⁽¹⁵⁾ obtained by this formula are claimed to fit the original data over the whole range (up to 20 m.f.p.) and for energies from 0.5 MeV to 10 MeV.

CHAPTER 3

EXPERIMENTAL ARRANGEMENTS

3.1 Teletherapy Sources

The Picker Caesium-137- "Cs-600 unit" and the "Theratron-80" cobalt-60 unit at the Dr. W.W. Cross Cancer Institute were used as the radiation sources for the experiments.

The caesium-137 source with a diameter of 3.2 cm is made up of a number of pressed caesium salt tablets. The caesium tablets are contained in a double welded stainless steel container, which in turn is assembled into a tungsten capsule. This container shields the beta radiation and prevents any escape of radioactive material. ^{137}Cs has a half life of 30 years and a gamma radiation of 0.661 MeV.⁽¹⁷⁾ The source output is 6 roentgens per minute at a distance of one meter as of July 1971. The sourcehead, position of the source and its collimation are shown in figure 3.

The cobalt-60 source is 2 cm in diameter and is made up of 1×1 mm nickel plated pellets. These pellets are doubly encapsulated by means of welding into inner and outer stainless steel capsules, which in turn are assembled into a tungsten capsule. This source is housed in a lead container, the sourcehead. ^{60}Co has a half life of 5.27 years and gamma radiations of 1.17

Fig.: 3
CAESIUM-137
"CS-600" UNIT

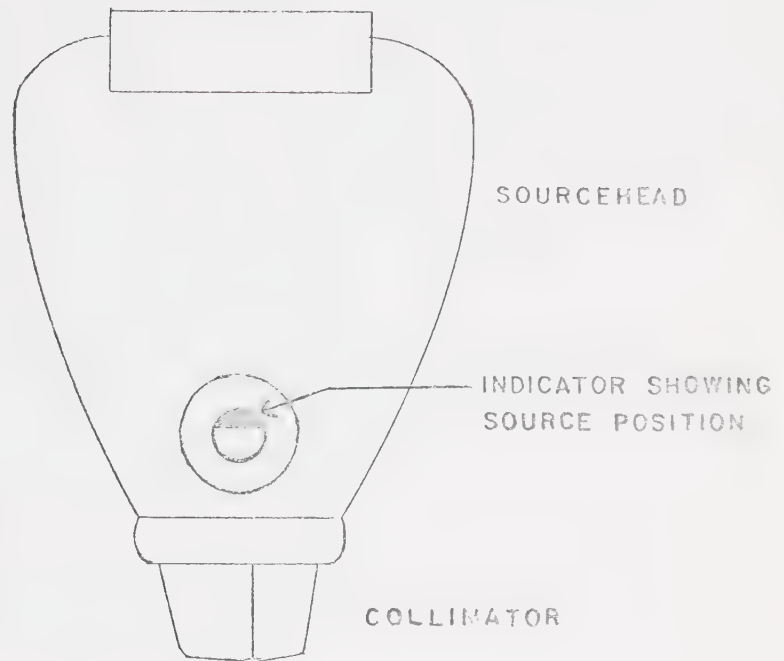
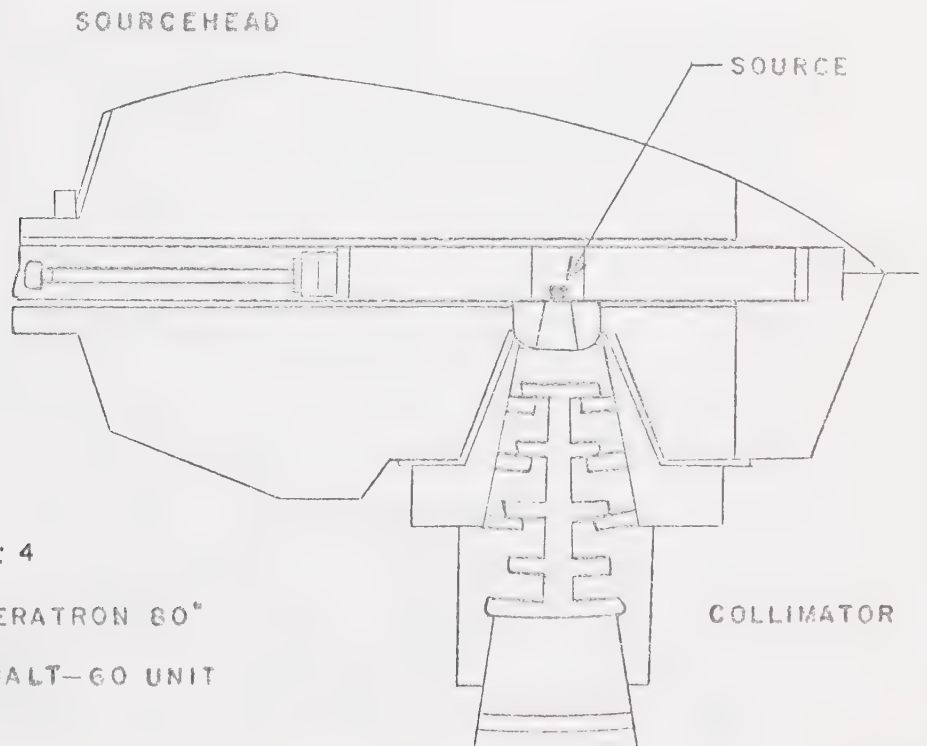


Fig.: 4
"THERATRON 80"
COBALT-60 UNIT



and 1.33 MeV. The source output is 92 roentgens per minute at one meter as of February 15, 1972. The sourcehead, position of the source and the collimation of the beam are shown in figure 4. A typical source capsule is shown in figure 5.

3.2 Thermoluminescence Dosimeter (TLD)

Thermoluminescent LiF powder type LiF-7 manufactured by the Harshaw Chemical Company, was studied and used for dosimetry in most of the measurements.

3.2.1 Mechanism of Thermoluminescence

The mechanisms involved in the thermoluminescence response of the powder to radiation are not yet fully understood. However, an accepted mechanism is based on the concept of the band theory of solids⁽¹⁸⁻²⁰⁾. The normally full band i.e. when the number of electrons in a band is the maximum allowed, is called the valence band. The next higher band normally empty, is called the conduction band. These bands are separated by an energy gap in which electrons are not normally allowed, the so called band gap. If two bands are sufficiently close to each other, electrons can go from the lower to the higher one as a result of thermal excitation even at normal temperatures. When the band gap is wide

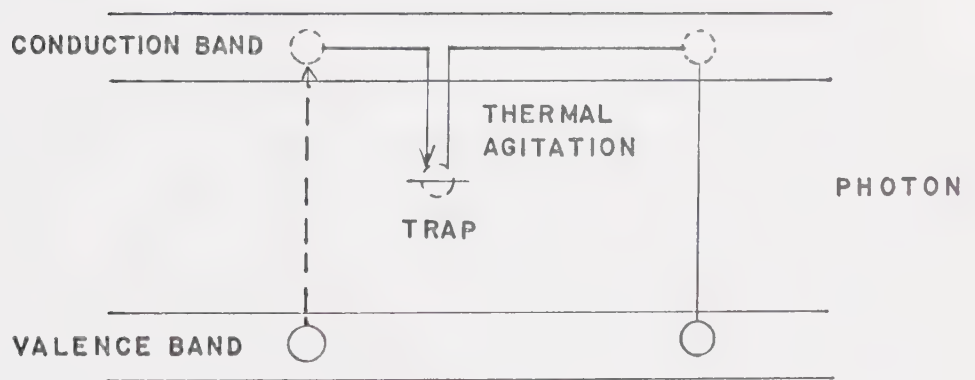
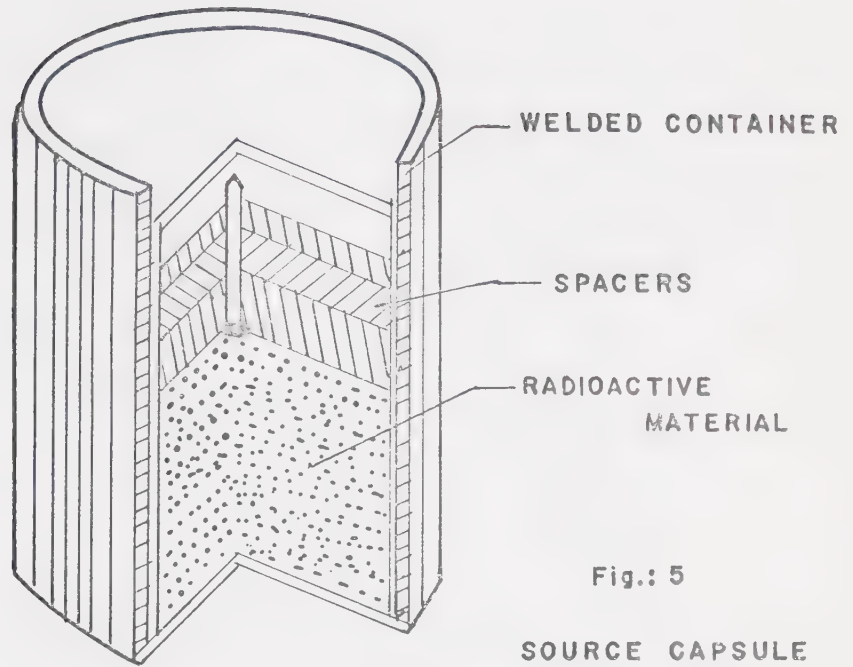


Fig.: 6

THERMALLY STIMULATED PHOSPHORESCENCE
(THERMOLUMINESCENCE)

enough, the transition of electrons across the gap is not possible at normal temperatures. This is the case in LiF where the band gap is about 12 eV.

Lattice imperfections in crystalline solids give rise to localized energy levels (traps) which are located in the band of energies between the valence band and the conduction band. When LiF powder is exposed to ionizing radiations, electrons 'jump' from the valence band to the conduction band by absorbing energy from these radiations. Some of the electrons return immediately to the valence band while others are trapped in localized energy levels. Only rarely do electrons escape from the traps and return directly to the valence band. Unless energy is supplied for their release, almost all the trapped electrons remain in the localized energy levels. If the powder is heated, the electrons acquire enough energy to be completely ejected from these traps into the conduction band, where they return to the valence band emitting a portion of initially absorbed energy in the form of visible light. This phenomenon of light emission is called Thermally Stimulated Phosphorescence or Thermoluminescence (figure 6). The total quantity of light thus emitted can be measured by a photomultiplier tube. This quantity may be related to the gamma exposure to which the thermoluminescent powder has been subjected.

A good TLD system should have the following characteristics:

- (1) The dosimeter used should have a high gamma radiation sensitivity and should be useful over a large range.
- (2) The light yield (number of photons emitted per gram per roentgen) should be independent of both the exposure and the energy of the radiation.
- (3) The dosimeter should have a minimum fading i.e. the number of trapped electrons should remain the same even if the powder is stored, after exposure, for extended periods of time.
- (4) The system used should have a good overall reproducibility.

3.2.2 Characteristics of LiF-7 Powder

Although the characteristics of LiF powder have been extensively investigated⁽²¹⁻²⁷⁾, some uncertainties still remain. It was therefore decided to study the characteristics of the powder to be used for the subsequent experimental measurements. The powder under study was divided into four different groups:

Group A - The fresh LiF-7 powder as supplied by the Harshaw Chemical Company.

Group B - Once irradiated and read powder.

Group C - Twice irradiated and read powder.

Group D - Multi irradiated and read powder which was annealed as per the standard annealing procedures⁽²⁸⁾, i.e. heating the powder at 400°C for one hour and then leaving it at a constant temperature of 80°C for 24 hours.

The irradiation of these different groups of powder was carried out utilizing the ^{60}Co and ^{137}Cs teletherapy units. A field size of 20 × 20 cm at 80 cm from the source was used for the ^{60}Co unit while a 10 × 10 cm field size at 27 cm from the source was used for the ^{137}Cs unit. The irradiation was also carried out with X-rays of different effective energies, generated by placing various filters in the beam, for quality dependence measurements. The different groups of powder were irradiated for different exposures.

A Con-Rad TLD Readout Instrument was used to read the irradiated powder. In this reader the powder is uniformly distributed and heated on a planchet and the amount of light emitted is measured by a photomultiplier tube. The total amount of light thus measured is presented on a digital voltmeter and is related to the gamma exposure. The block diagram of the TLD-reader is shown in figure 7.

A standard light source whose light output can be considered to be constant with time was used to set the sensitivity of the instrument before reading the dosimeters.

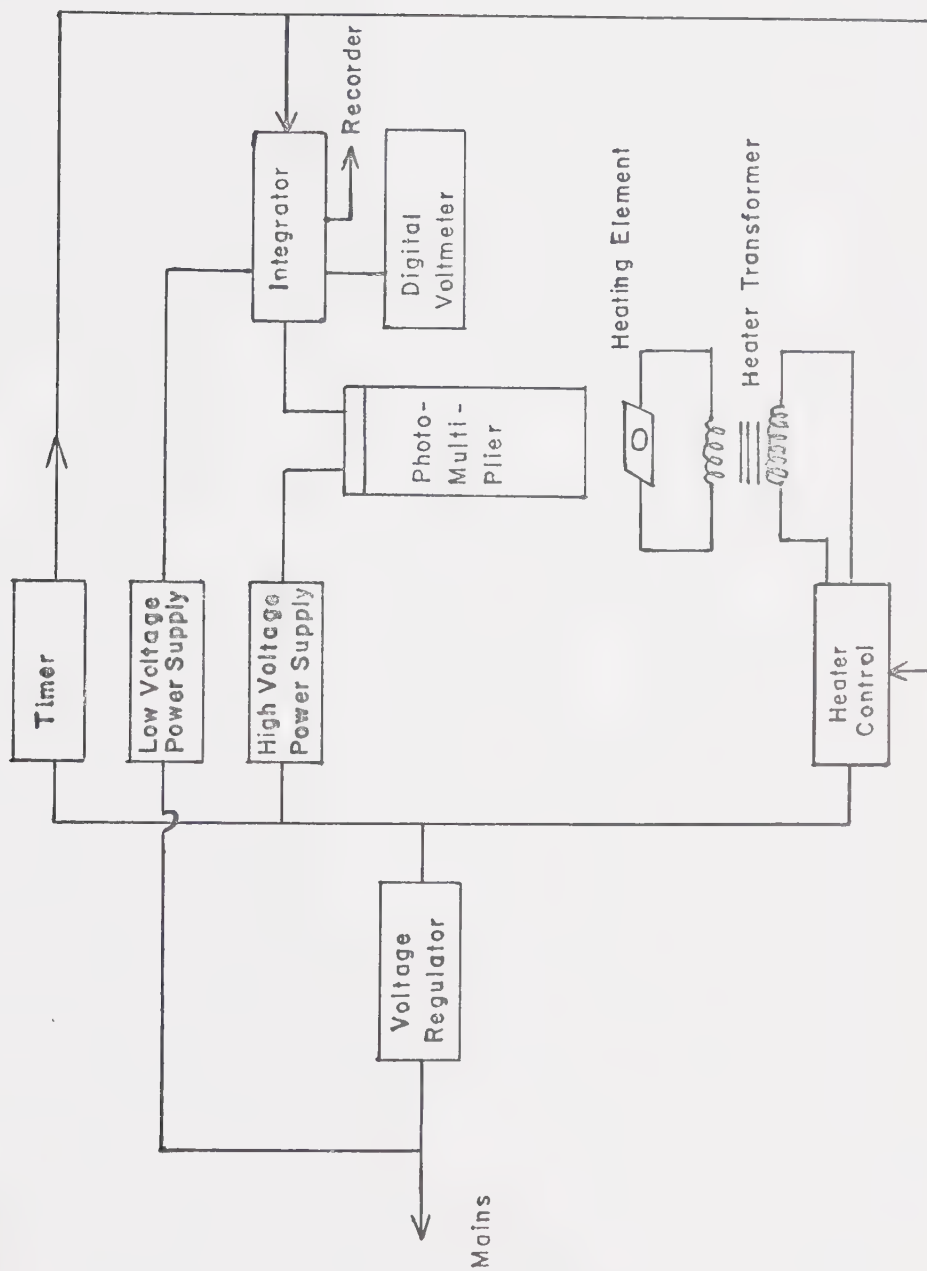


Fig.: 7

BLOCK DIAGRAM OF TLD READER

As the light output is proportional to the amount of powder utilized, equal amounts of powder were read for each exposure. A vibrating dispenser was used for dispensing equal amounts of powder each time. The consistency of the dispenser was checked by weighing the dispensed samples on an analytical balance. The standard deviation over 40 aliquots was found to be 0.51%. The average weight of the powder per aliquot was 40.55 mg. The following characteristics were found:

The sensitivity of group B and group C powder was found to be double the sensitivity of group A i.e. fresh powder. Quantitatively this increased sensitivity was found to be 20 digits per rad for 40.55 mg of powder when the high voltage applied to the photomultiplier tube was such that the standard light source read 500 digits on the digital voltmeter. This increase was observed to be due to preheating the fresh powder through the heating cycle of the TLD-reader. The sensitivity of group D i.e. annealed powder, was found to be the same as that of fresh powder. Thus, the enhanced sensitivity of the powder, passed through the heating cycle, was reduced to its original value by annealing. It was also observed that there was a background reading of 80-100 digits for group B and group C powder for the same standard light source reading of 500 digits. There was no appreciable background reading for group A and

group D powder. Thus, the fresh powder was reused without annealing for total dose of 25 rads or more.

The different groups of powder were irradiated with the ^{137}Cs unit to check the response of the powder with absorbed dose. The range of the irradiation was 5-1000 rads. The light output was found to be directly proportional to the magnitude of absorbed dose over the entire range. The linear response with absorbed dose is shown for a typical group of powder in figure 8.

The response of the powders was found to be independent of energy between 137 KeV (3 mm of Cu HVT) and 1.25 MeV (15 mm of Cu HVT). The corresponding values of the effective energy and half value thickness (HVT) were obtained from the British Journal of Radiology supplement no. 11⁽²⁹⁾. The maximum variation in response in this energy range was observed to be ~5%. For lower energies the energy dependence was significant, with an enhanced response of up to 40% relative to the response at 1.25 MeV. The relative light yield with energy of radiation for group A powder is shown in figure 9. Commercially available wire mesh, intended to give a similar response in the low energy region to that for ^{60}Co radiation was found to have little effect on this enhanced response at low energies (refer to figure 9).

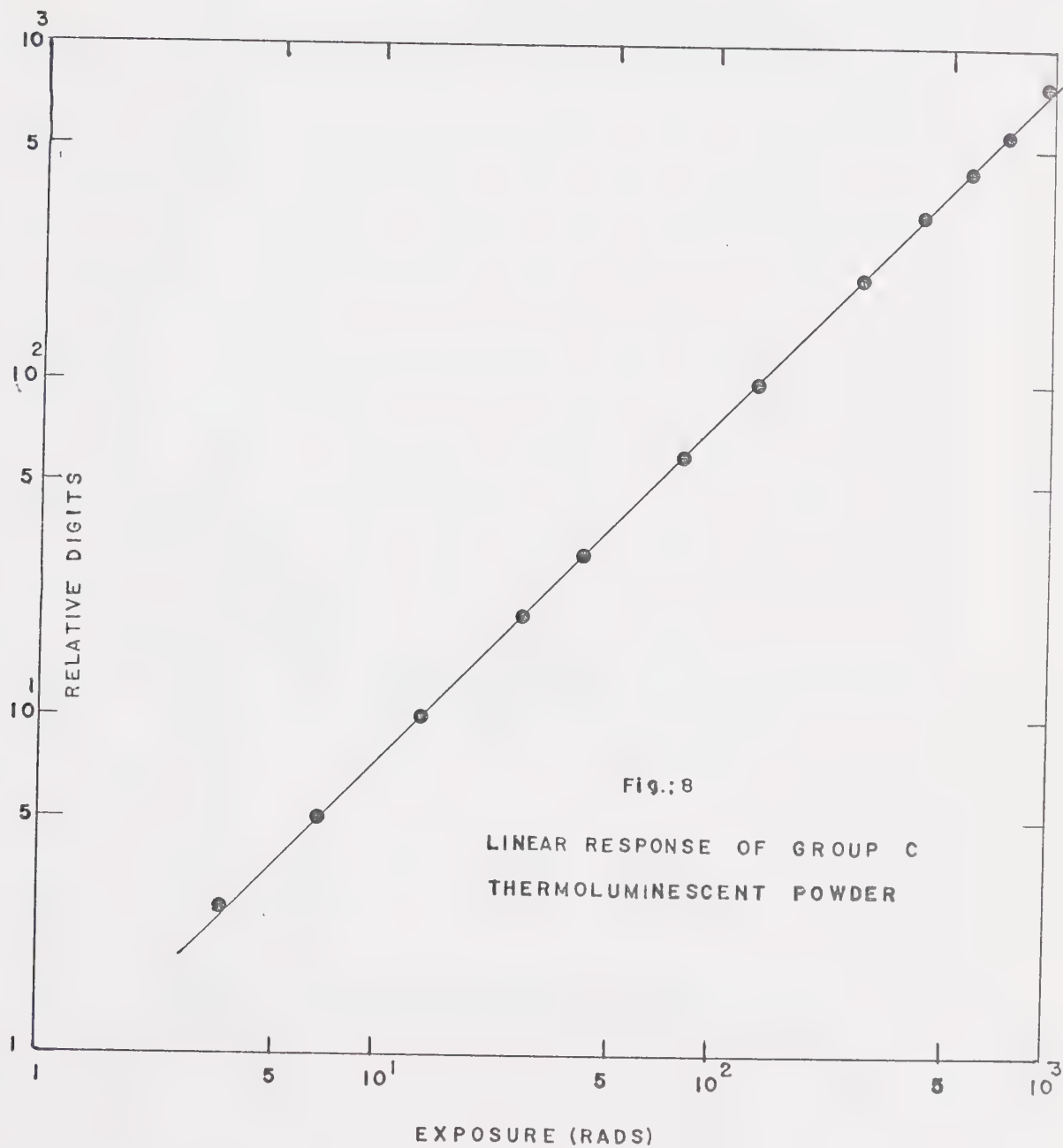
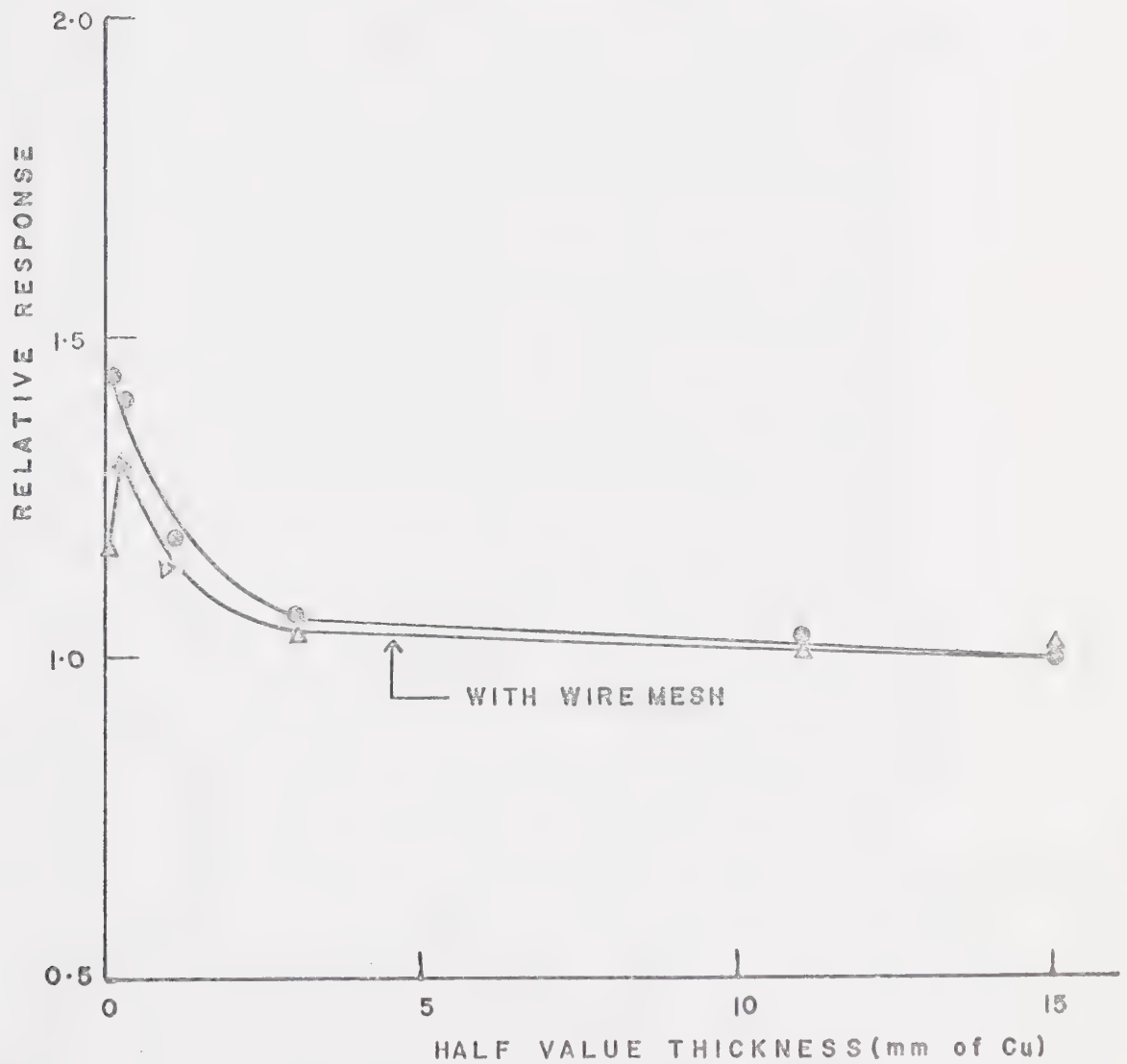


Fig.19

QUALITY DEPENDENCE OF GROUP A
THERMOLUMINESCENT POWDER



The fading of the different groups of powder was observed to be about 10% in the first 40 hours, and after that the fading was less than 1% per two days up to 25 days. After 25 days there was practically no fading; less than 1% over 75 days. The fading with time for group B powder is shown in figure 10.

The overall reproducibility of all the different groups of powder was found to be good. It showed a standard deviation of $\pm 2\%$ over many sets of 20 observations each.

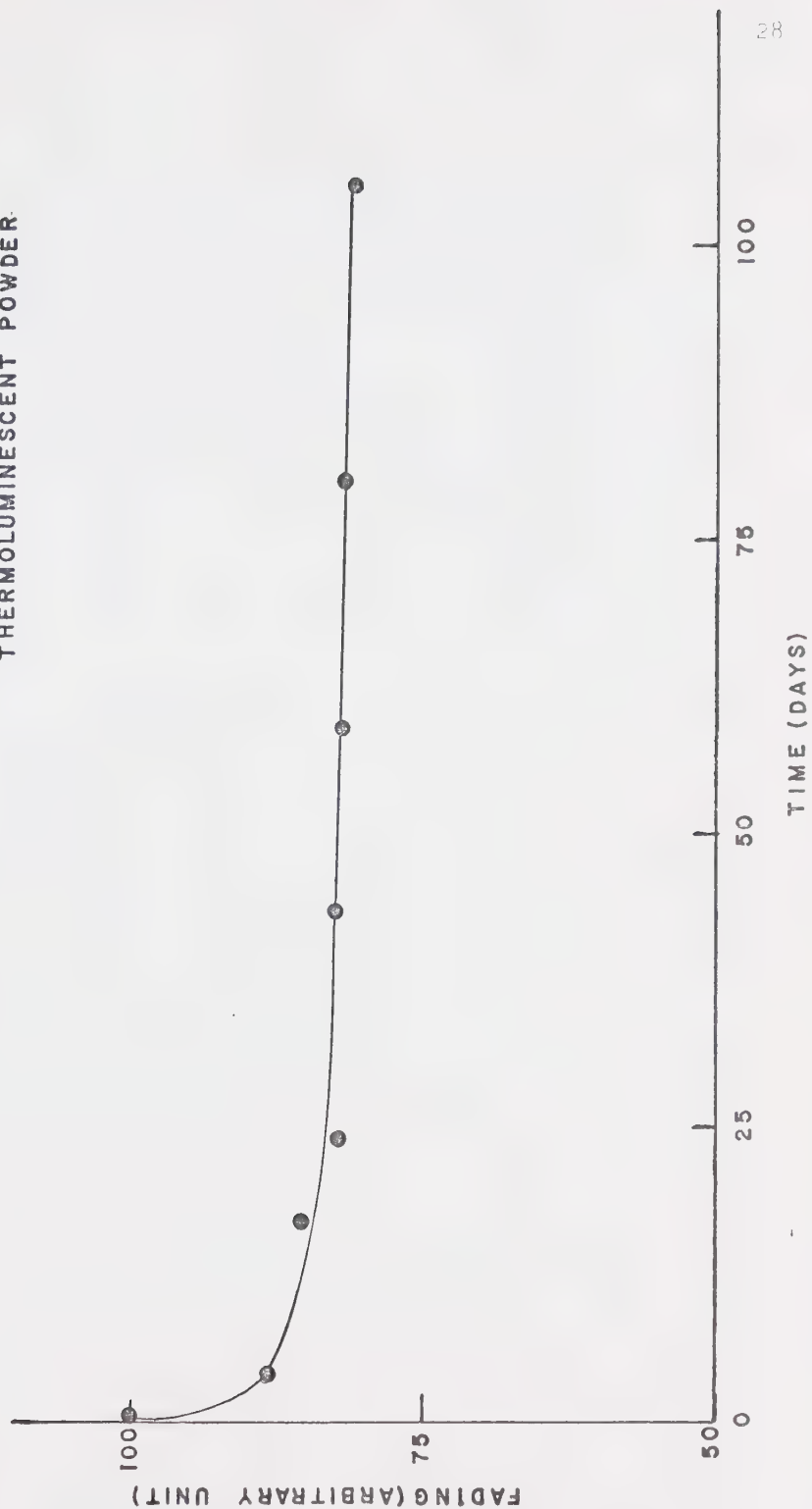
Having observed these characteristics, the LiF powder was used for dosimetry. Because of the fading properties described above, the practice of reading the powder one or two days after irradiation was instituted.

3.3 Setup for the Buildup Measurements

The measurements were carried out with ^{137}Cs and ^{60}Co teletherapy units. Although thermoluminescence dosimeters were used for most of the measurements, ionization chambers were also utilized. The absorbing materials studied were lead, iron and water. The lead and iron absorbers were in the form of 15×15 cm plates with an average thickness of 3.4 mm and 9.6 mm respectively. For water as an absorbing material a polyethylene container of diameter 57 cm and height 90 cm filled with water was used.

Fig. : 10

FADING OF THE GROUP B
THERMOLUMINESCENT POWDER



For the ^{137}Cs unit the measurements were carried out with a circular beam of 14 cm diameter at 15 cm from the source. The absorbing materials were placed between the source and the detector. The thickness of the absorbers was varied by the number of plates in the cases of lead and iron and by the level of water in the polyethylene container in case of water. The detectors (TLD and/or ionization chambers) were placed at three different positions behind the absorbing material:

(a) Just behind the absorbing material, $x = 0$.

(b) At a distance of 10 cm from the absorber,
 $x = 10$ cm.

(c) At a distance of 20 cm from the absorber,
 $x = 20$ cm.

The experimental setup used for these measurements was as shown in figure 11. The total exposure was kept within the sensitivity of the detector by varying the time of exposure. The measurements were repeated at the same positions without any absorbing material in the beam.

For the ^{60}Co teletherapy unit the measurements were carried out with a field size of 20×20 cm at 80 cm from the source. The lead and iron absorbers were placed on a lucite plate attached to a frame on the unit. The detectors were placed behind the absorbing materials at the same three positions as

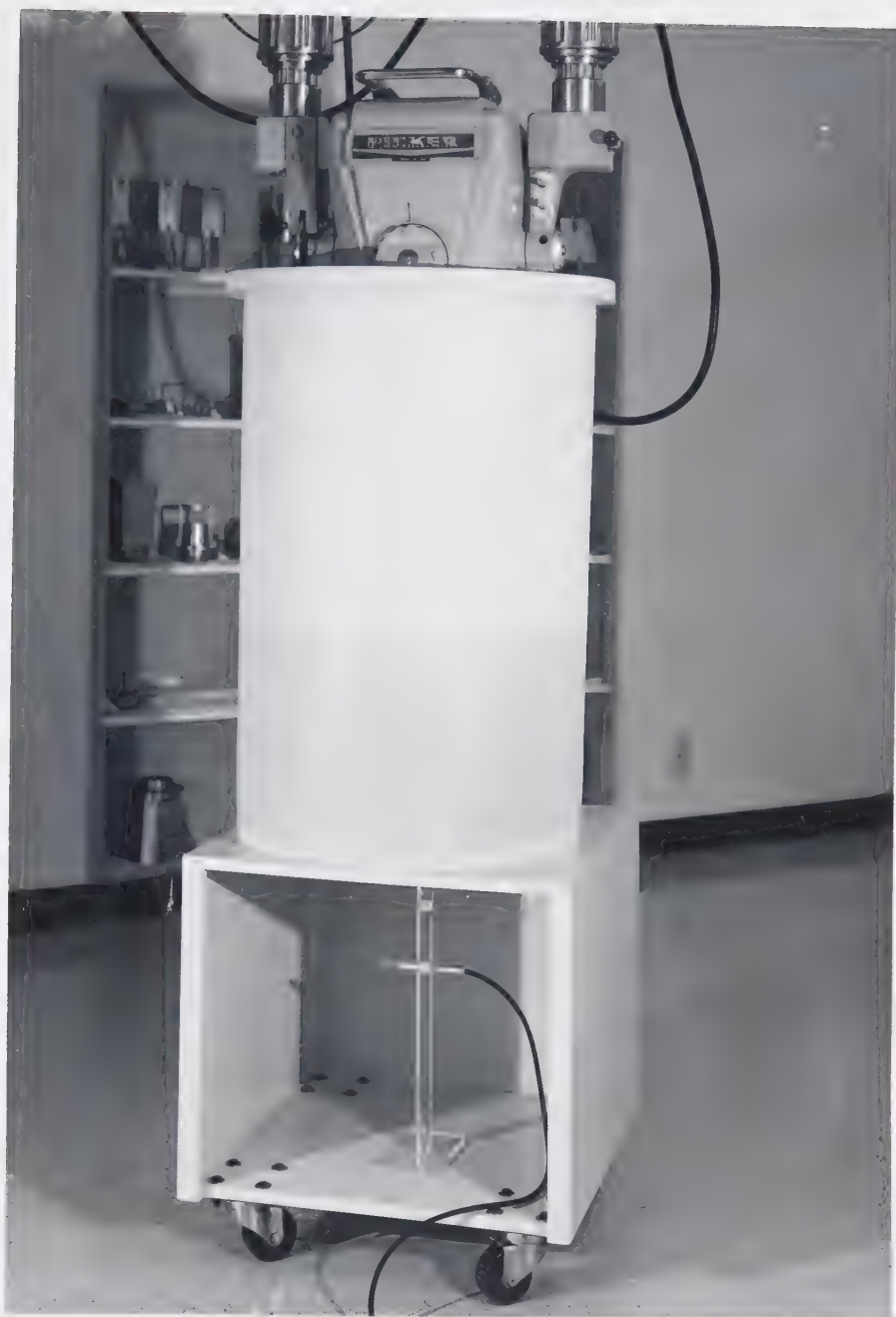


Fig.: 11

Experimental arrangements with ^{137}Cs unit

in the case of ^{137}Cs unit. The experimental arrangement was as shown in figure 12. For the measurements with water as an absorber the container was placed on a wooden trolley. A slit of 8×16 cm was cut in the middle of the top surface of the trolley such that the detectors could be placed just touching the bottom of the container. The container was placed in the beam with the detector at the same three positions as with lead and iron absorbers. The measurements were also made without any absorber in the beam, as in the case of ^{137}Cs unit. The measurements were carried out with a thickness of upto four mean free paths of the absorbing material for both ^{137}Cs and ^{60}Co units.

3.4 ^{137}Cs Sealed Sources and the Cervix Applicators

The ^{137}Cs sealed sources under consideration were in the form of a pencil of length 2 cm and diameter 0.265 cm with an active length of 1.35 cm. The strength of the sources varied from 30 mCi to 75 mCi. All the sources had 0.5 mm of platinum shield.

Applicators, consisting of an intrauterine tube and a vaginal applicator are used for the treatment of carcinoma of the cervix uteri. The shape and size of the applicators depend upon the anatomical location and size of the tumours to be treated. These applicators are inserted into the body cavities for purposes of



Fig.: 12

Experimental arrangements with ^{60}Co unit

treatment. The cervix applicators under consideration are described below:

The standard intrauterine tube is a stainless steel closed tube of length 6.35 cm with inner and outer diameter of 0.275 cm and 0.476 cm respectively (figure 13). The bottom end of the tube is closed with a screwed stainless steel flange (refer to figure 13). The standard intrauterine tube was loaded with three ^{137}Cs sealed sources, 45 mCi at the top end followed by two 30 mCi sources.

The vaginal applicator is constructed of segments of perspex. Up to a maximum of three similar ^{137}Cs sealed sources are loaded into a closed steel tube which is inserted into another steel tube of length 16.5 cm and inner diameter 0.625 cm. This tube is surrounded by the perspex segments, with or without built in lead absorber, of the applicator. The whole assembly, perspex segments and steel tubes, is held together on a screwed thread. Two ^{137}Cs sources of equal strength were used at a time. The measurements were carried out with 60 mCi and 75 mCi sources. The vaginal applicator studied was as shown in figure 14.

3.5 Radiation Distribution Measurements around Cervix Applicators

The measurements of the radiation distribution

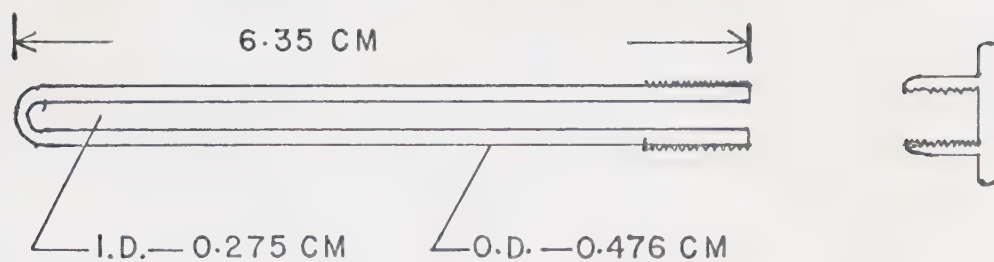


Fig.: 13

INTRAUTERINE TUBE

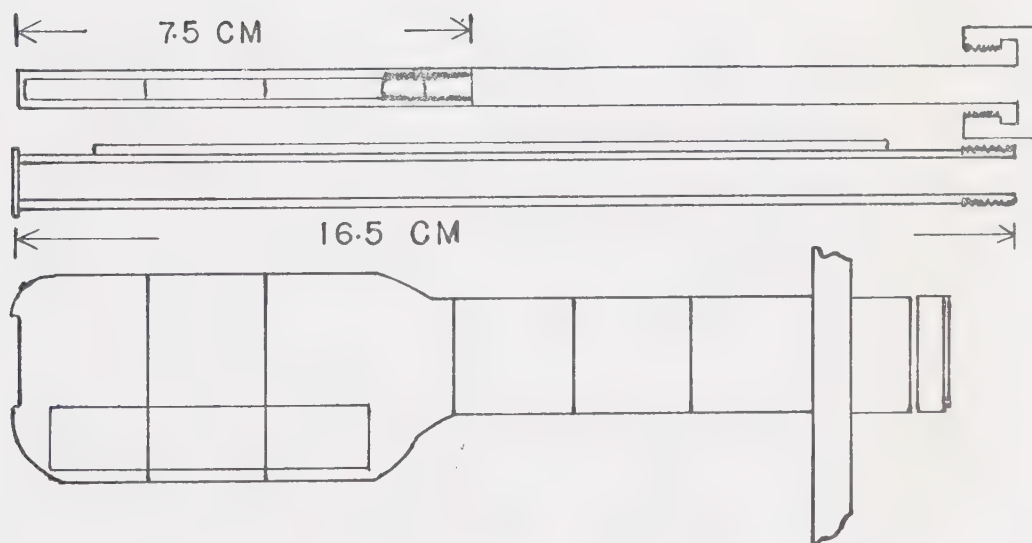


Fig.: 14

VAGINAL APPLICATOR

around the cervix applicators were made by using TLD. The TLD was preferred since the other detectors available were of large dimensions and therefore had poor spatial resolution. Kodak Blue Brand Medical X-ray film was also tried for these measurements. The film was found to be dependent upon the quality of radiation and conditions under which the film was processed and thus was not suitable for radiation distribution measurements in tissue equivalent medium. However, there are various other reasons such as directional dependence for which accurate dosimetry is difficult with photographic film⁽³⁰⁾. In view of the characteristics of the LiF powder mentioned earlier in 3.2.2, it was felt that the use of small volumes of powder would lead to mapping of the radiation distribution close to the sources with adequate accuracy.

Small lucite cups of inner diameter 2 mm and depth 2.5 mm were made. About 20 cups were filled with LiF-7 powder for statistical measurements. The amount of the powder in each cup was weighed on an analytical balance. The standard deviation over 20 weighings was found to be $\pm 2.5\%$. The average weight of the powder in a lucite cup was 12.293 mg. For the radiation distribution measurements these cups were filled with LiF-7 powder and distributed in a lucite plate ($16 \times 16 \times 0.625$ cm thickness). The applicator was placed in the middle

of the lucite plate. As the cervix applicators are inserted into body cavities during treatment, it was desirable to do the irradiation in a tissue equivalent material. Thus, the irradiation of the LiF powder was carried out in a pressedwood medium ($20 \times 24 \times 27$ cm). The total exposure time varied between 5 and 25 hours depending upon the source strength and the distance of the point of interest from the source.

CHAPTER 4

EXPERIMENTAL RESULTS

We have discussed and defined the buildup factor earlier in Chapter 2. In this chapter we give the experimental results and compare them with the theoretical data of the moments method for plane parallel sources, corrected for a finite medium by the Berger and Doggett⁽³¹⁾ formula:

$$k(t) = \frac{B(t,t) - 1}{B(t,\infty) - 1}$$

or

(12)

$$B(t,t) = 1 + k(t)[B(t,\infty) - 1]$$

where $k(t)$ is the buildup factor ratio for a given thickness of the absorbing material and the energy of the gamma radiation, $B(t,\infty)$ is the buildup factor at depth t in an infinite medium and $B(t,t)$ is the buildup factor for a finite thickness t of the absorbing material. The values of $B(t,t)$ obtained from this formula have been found to be in good agreement with the experiments^(32,33).

The value of $k(t)$ was obtained from Table 3 of the Berger and Doggett⁽³¹⁾ paper. This table has been reproduced here as table 1. The value of $B(t,\infty)$ was

Table 1

Buildup factor ratio $k(t) = [B(t,t)-1]/[B(t,\infty)-1]$
 for comparing transmission of radiation through
 a finite barrier with penetration to an equal
 depth in a semi-infinite medium

Material	Energy MeV	μx					
		^a 1.0	1.0	2.0	4.0	8.0	16.0
Water	0.66	0.601	0.663	0.713	0.783	0.785	0.784
	1	.661	.720	.754	.821	.828	.830
	4	.849	.885	.912	.920	.926	.933
Iron	1	.790	.798	.851	.890	.895	.894
	4	.890	.910	.923	.936	.932	.949
	10	.941	.959	.972	.974	.978	.977
Tin	1	.889	.911	.924	.935	.938	.946
	4	.941	.926	.955	.967	.974	.978
	10	.951	.960	.962	.973	.971	.969
Lead	1	.939	.951	.969	.975	.979	.982
	4	.941	.977	.982	.990	.992	.994
	10	.986	.990	.995	.992	.994	.995
Estima- ted accuracy (%)	---	±5.0	±2.0	±1.5	±1.5	±2.0	±2.5

^a Comparison of a barrier with an infinite medium.

obtained from the theoretical data of the moments method. This data has been verified experimentally by many researchers⁽³⁴⁻³⁶⁾. $B(t,t)$, the buildup factor for a finite thickness of the absorber was then calculated from the formula 12. The buildup factors for the finite cross-section of the beams as observed experimentally were compared with these theoretical values.

4.1 Buildup Factors for ^{137}Cs and ^{60}Co Radiations

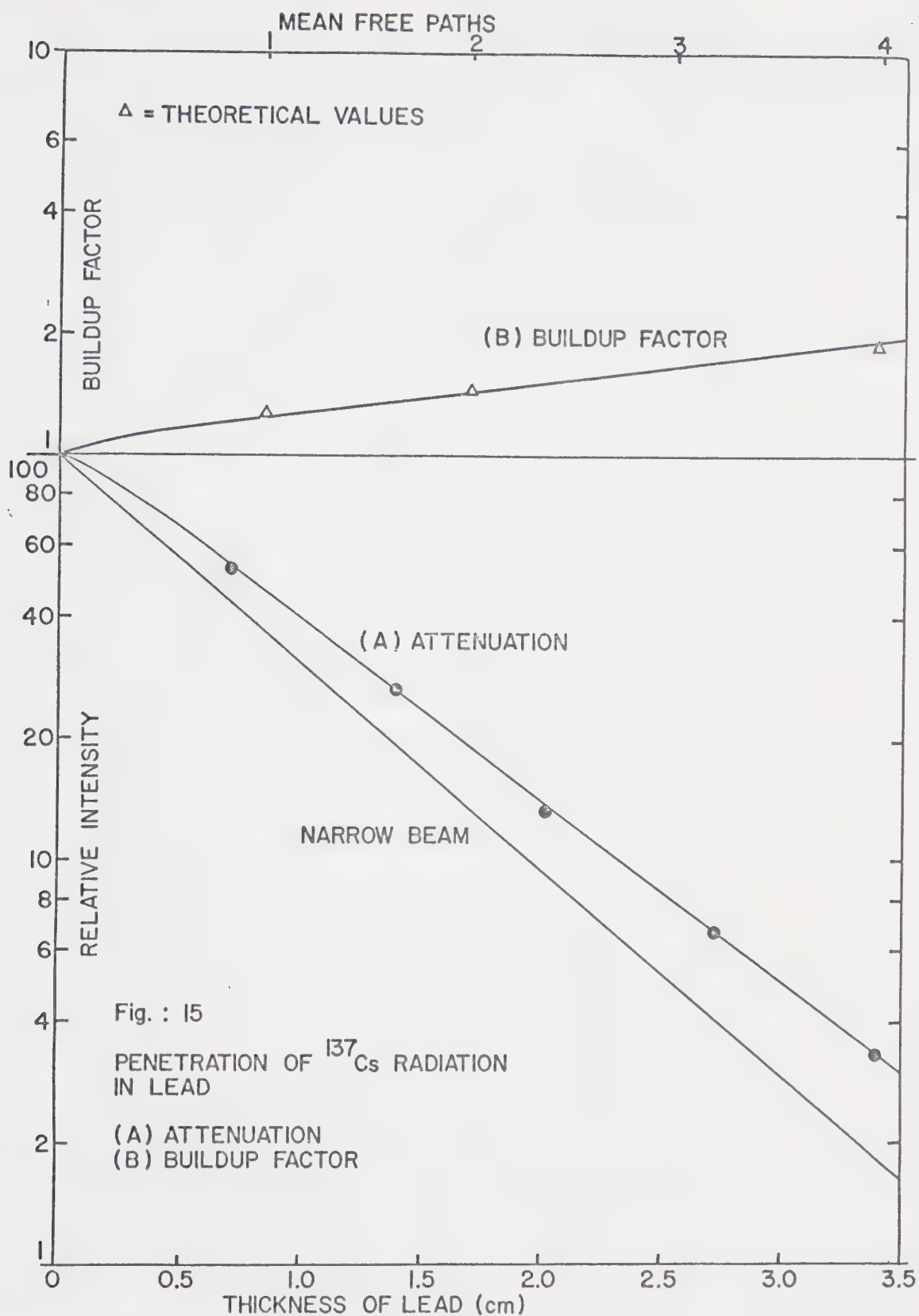
Buildup factors for lead, iron and water were determined experimentally for thicknesses of these materials up to four mean free paths. The measurements for the ^{137}Cs source were carried out with a gamma beam of field size 14 cm in diameter at 15 cm from the source, while for the ^{60}Co source a gamma beam of 20×20 cm at 80 cm from the source was employed. The measurements were carried out with the detector placed just behind the absorbers. The observed values were normalized to 100, corresponding to the detector reading without any absorber in the beam. Graphs were plotted for relative intensity at the detector versus thickness of the absorbing materials for both the ^{137}Cs and ^{60}Co radiations. These graphs are shown in figures 15-20A. The upper solid curves in these graphs represent the attenuation of the radiations with the detector placed just behind

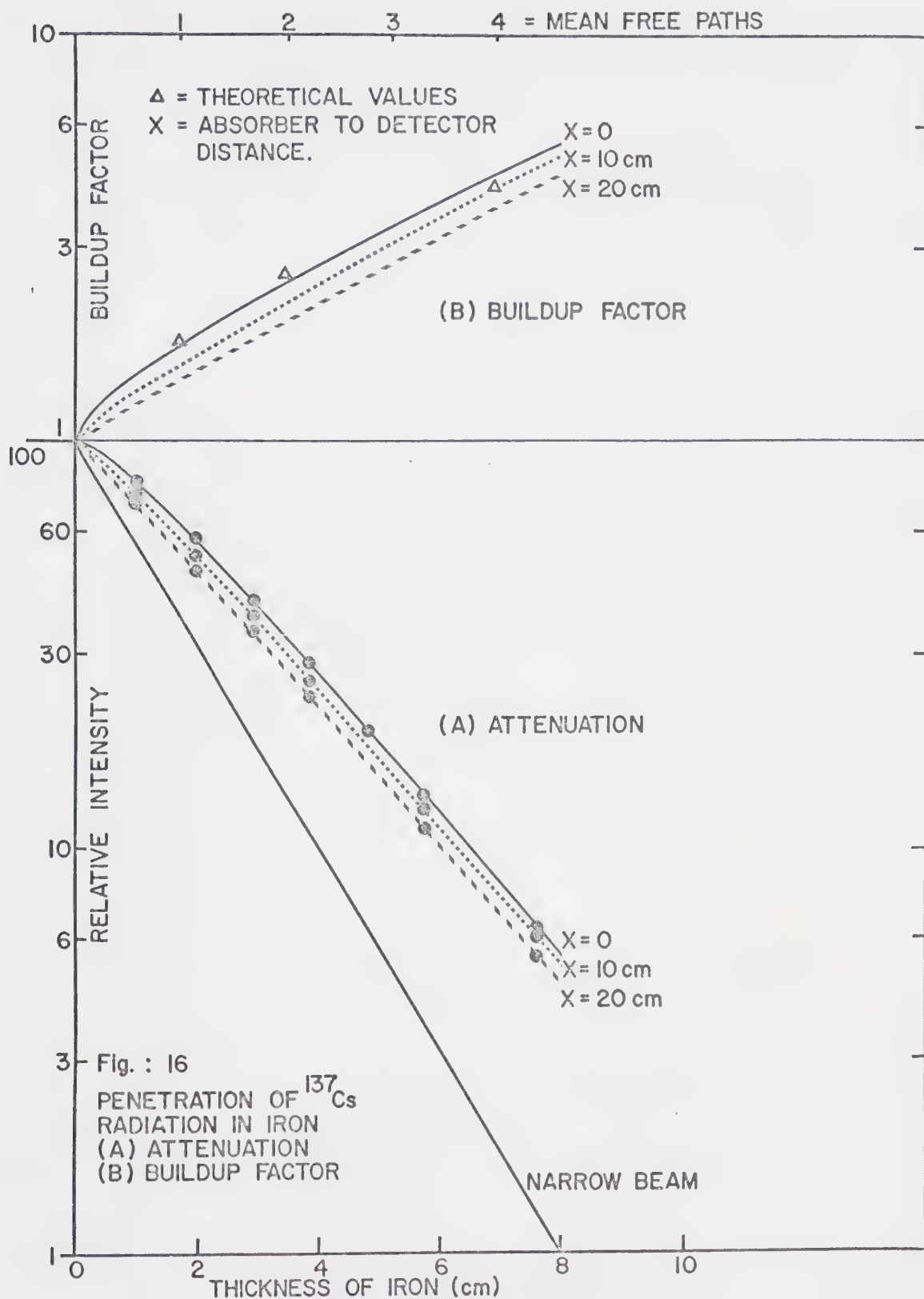
the absorbing materials. The lowest solid curves represent the narrow beam attenuation, characterized by $I = I_0 e^{-\mu x}$, with $I_0 = 100$ and the values of μ as obtained from Hubbell's data⁽³⁷⁾. The thickness of one mean free path for different absorbing materials was also calculated from these μ values as

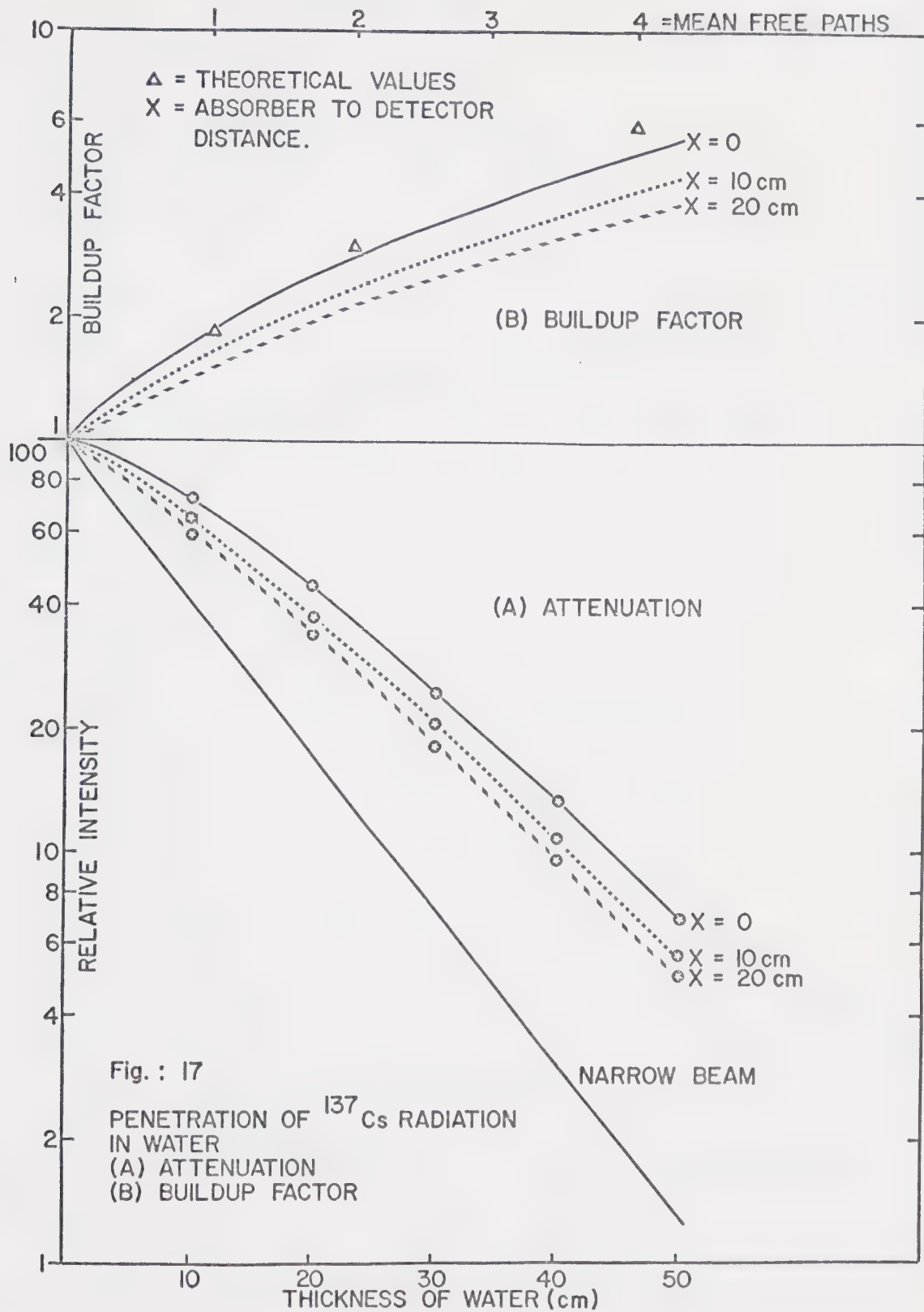
$$1 \text{ mean free path} = \frac{1}{\mu} \text{ cm} .$$

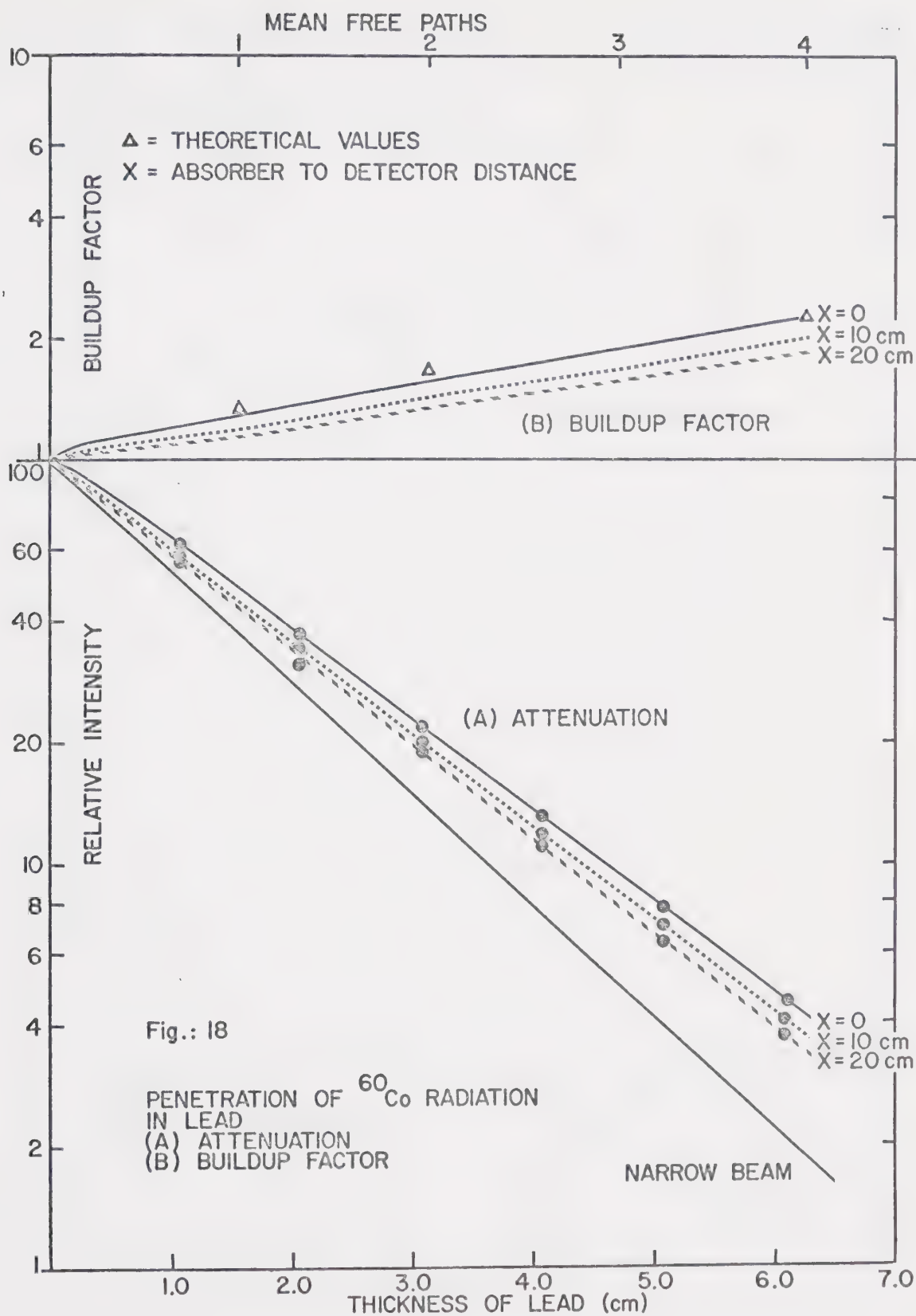
Buildup factors i.e. the ratio of the observed normalized values to the calculated values of narrow beam attenuation, were plotted for different thicknesses of the absorbing materials upto four mean free paths. These values of the buildup factors for different absorbers are shown by the solid curves in figures 15-20B. The small triangles (Δ) represent the theoretical values obtained from the moments method data as described at the beginning of this chapter.

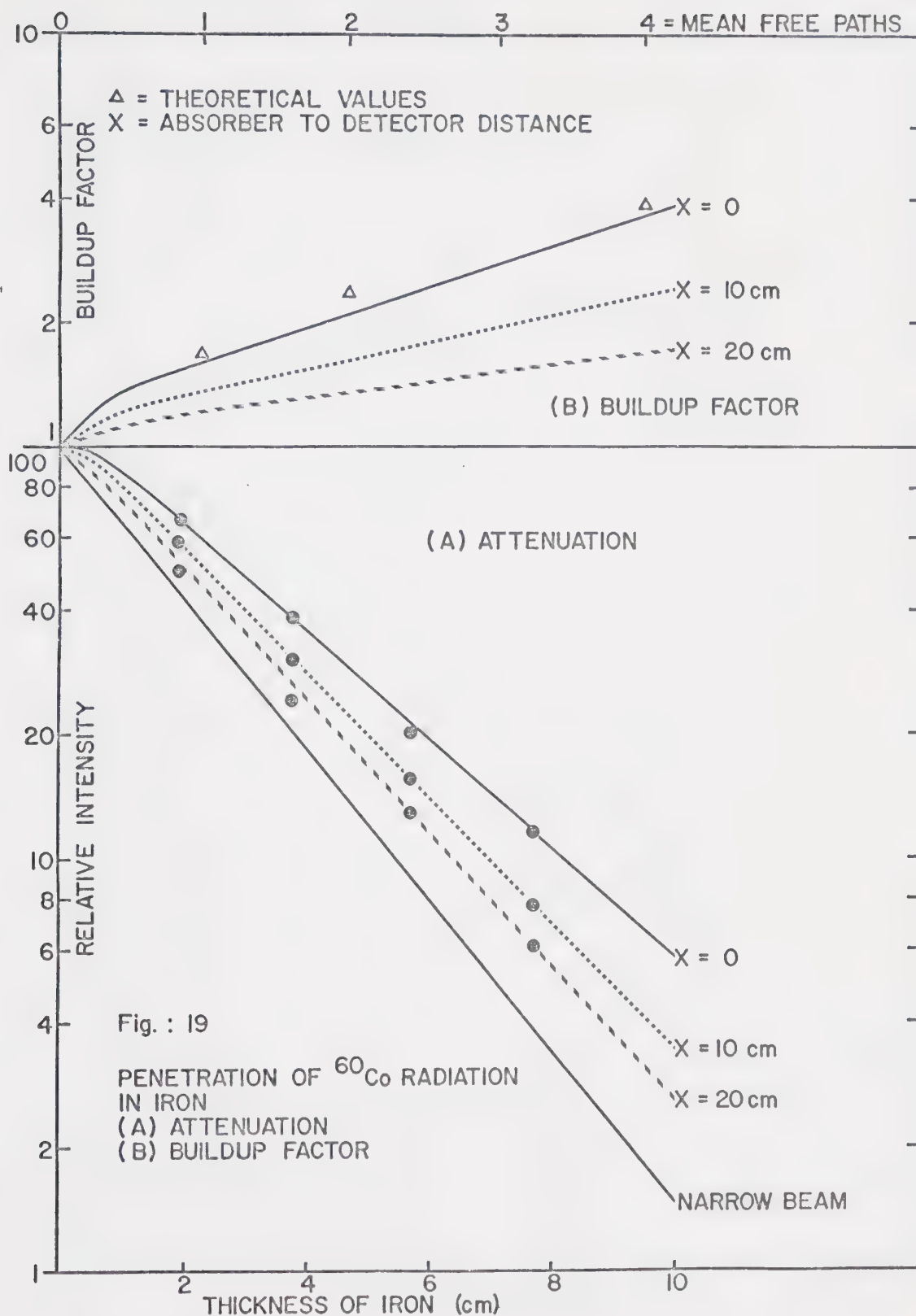
The measurements carried out with the detector placed at 10 cm and 20 cm away from the rear of the absorbing materials, to observe the effect on the buildup factors of the detector position are also shown in figures 15-20A and B for both ^{137}Cs and ^{60}Co radiations. The two dotted curves in figures 16-20A represent the relative intensity at the detector placed at 10 cm and 20 cm away versus thickness of the absorbers. The change in the buildup factors with these detector

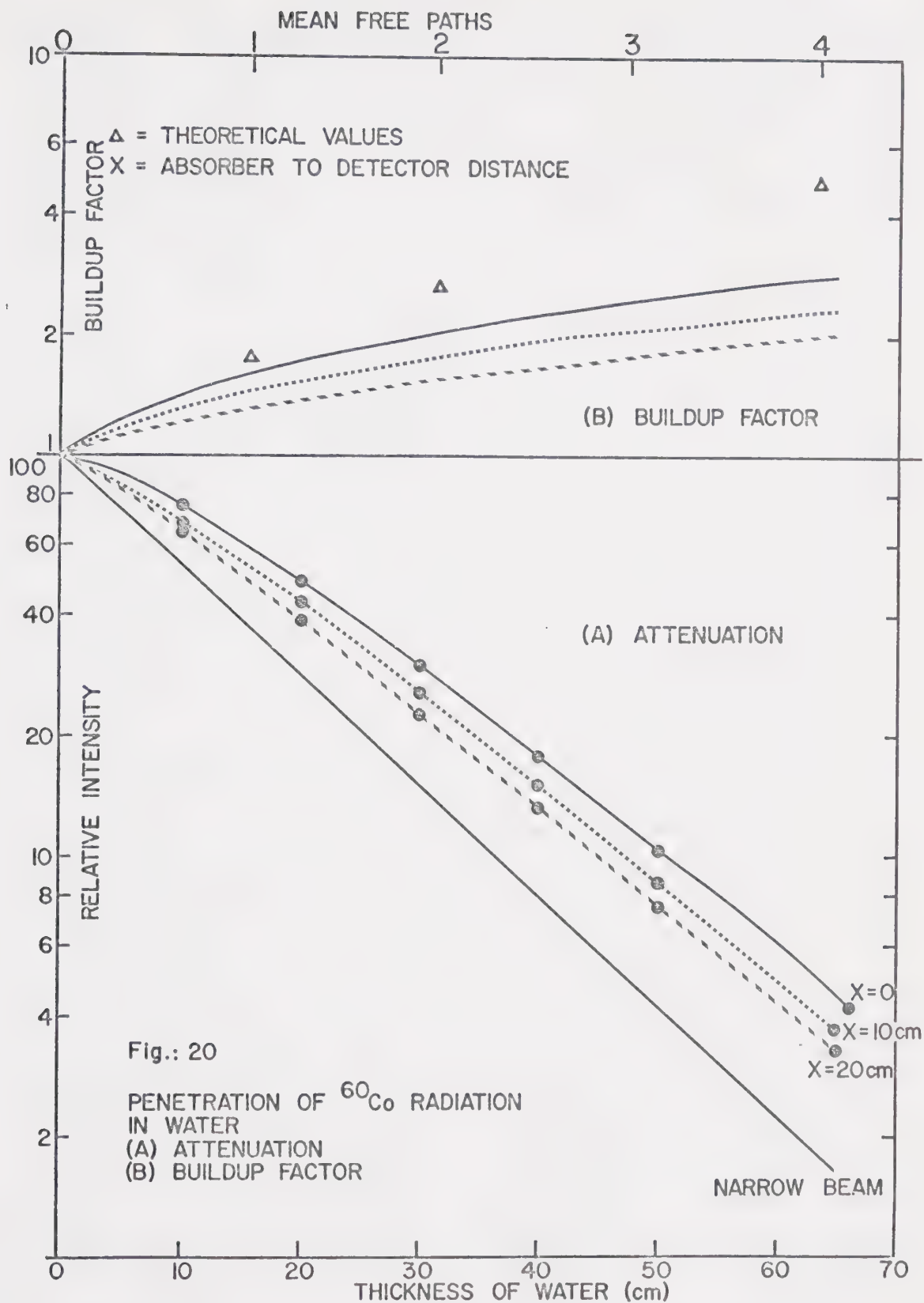










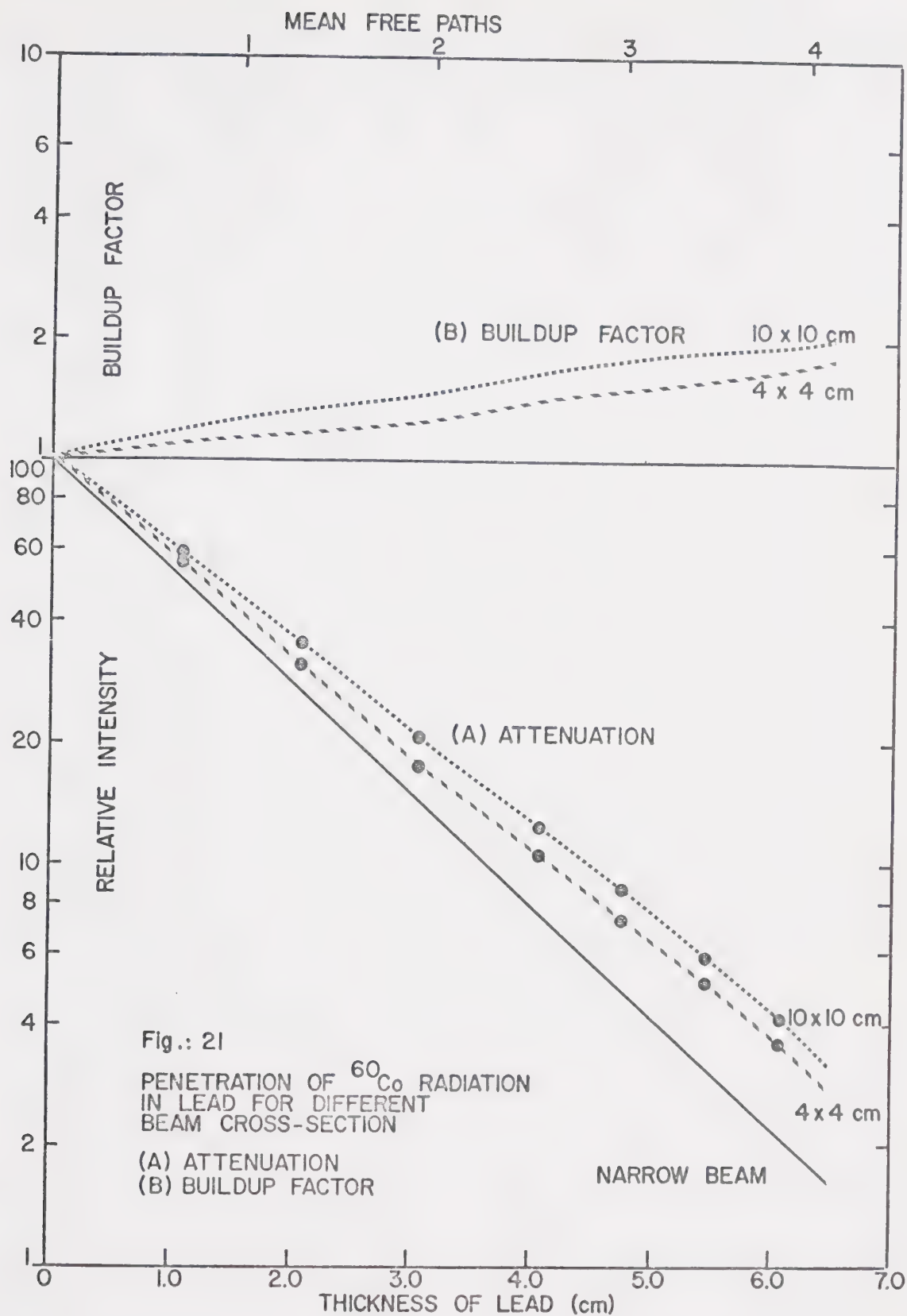


positions is shown by the dotted curves in figures 16-20B. This change in the buildup factors with detector position was quite distinct for different absorbing materials. There was no appreciable change in the buildup factors of lead with detector position for ^{137}Cs radiation.

For clinical interest the buildup factors for a ^{60}Co source with lead as an absorbing material were determined experimentally for two more field sizes of the beam. The field sizes used were 4×4 cm and 10×10 cm at 80 cm from the source. These attenuation curves and the buildup factor curves for different thicknesses of lead are shown by the dotted curves in figures 21A and B respectively.

4.2 Radiation Distributions around ^{137}Cs Line Sources

The radiation distribution measurements were carried out by distributing the TLD cups in a lucite plate with the applicator in the middle of the plate. The irradiation of the TLD was done in a pressedwood medium. The measurements were made up to 7 cm from the axis of the applicator and up to 7 cm along the applicator from its center. These measurements were done for a variety of ^{137}Cs line sources such as single line source and a combination of line sources. Intrauterine tube and vaginal



applicators (with and without lead shield) were used as containers for different combinations of these line sources. The dose distribution measurements for the different applicators were plotted as isodose curves. These isodose curves are shown in figures 22-25. The isodose curves for a typical combination of the intra-uterine tube and vaginal applicator are shown in figure 26. It was observed that the superposition of the isodose curves of intrauterine tube and vaginal applicator placed in the same positions as in the combined cervix applicator, gives the same isodose plot as obtained experimentally. Thus, the isodose curves of the individual sources could be used to determine the dose rate at any point of interest for any geometrical distribution of line sources. The experimental observations of the radiation distribution around single ^{137}Cs line source were compared with the Young and Batho⁽³⁸⁾ data and with the values obtained from dose rate calculations, considering a line source as a series of point sources, as given in Appendix A. This point source approximation has been described in detail in Chapter 5.

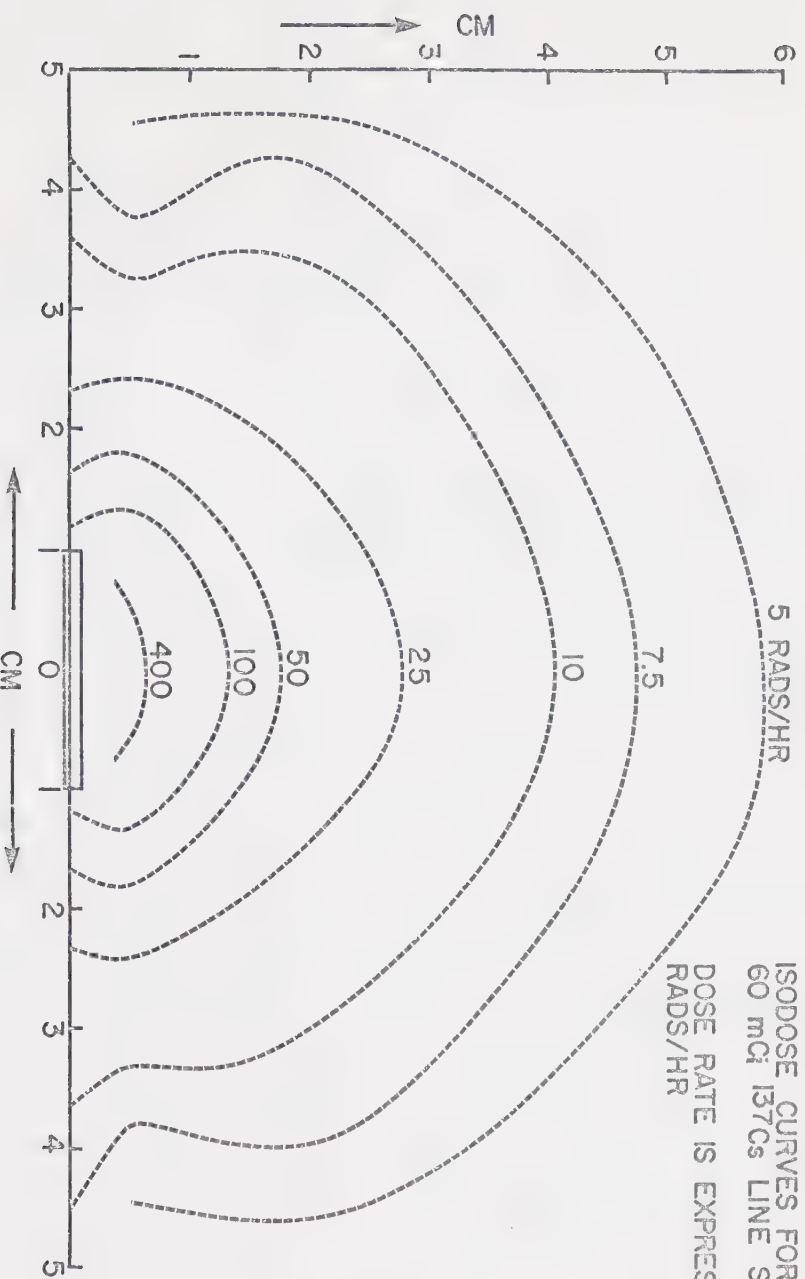


Fig.: 22
ISODOSE CURVES FOR A
60 mCi ¹³⁷Cs LINE SOURCE
DOSE RATE IS EXPRESSED IN
RADS/HR

Fig. : 23

ISODOSE CURVES FOR INTRAUTERINE TUBE
LOADED WITH TWO 30mCi AND ONE 45mCi
 ^{137}Cs LINE SOURCES

DOSE RATE IS EXPRESSED IN RADS/HR

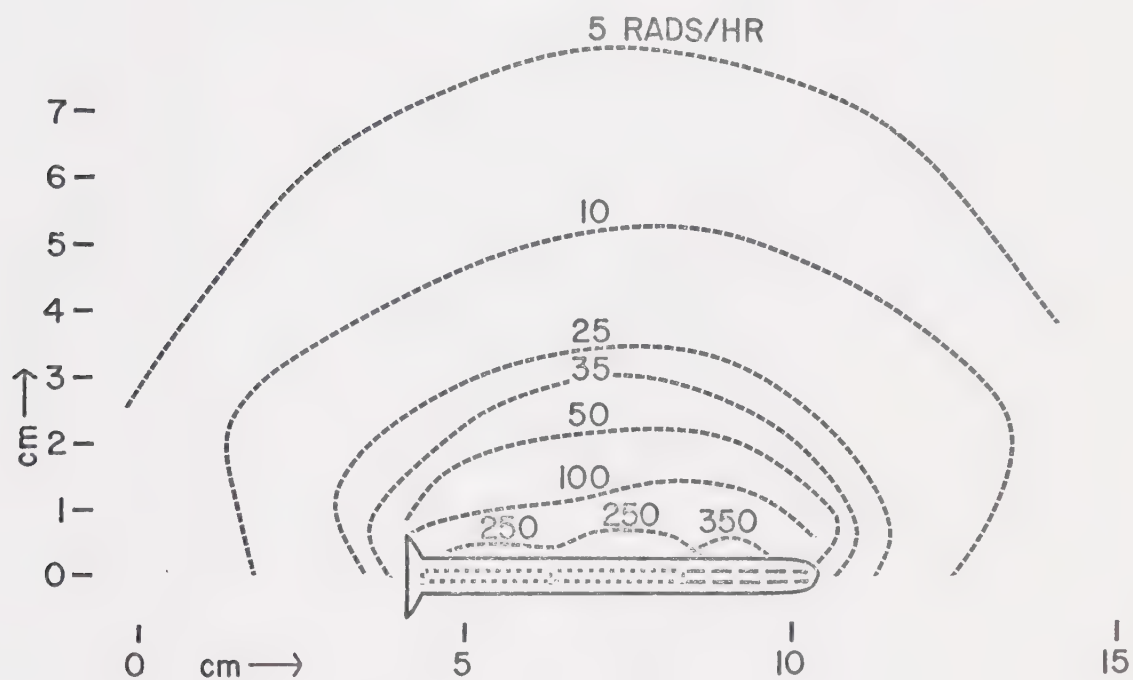


Fig. : 24

ISODOSE CURVES FOR VAGINAL APPLICATOR
LOADED WITH TWO 75mCi ^{137}Cs LINE SOURCES

DOSE RATE IS EXPRESSED IN RADS/HR

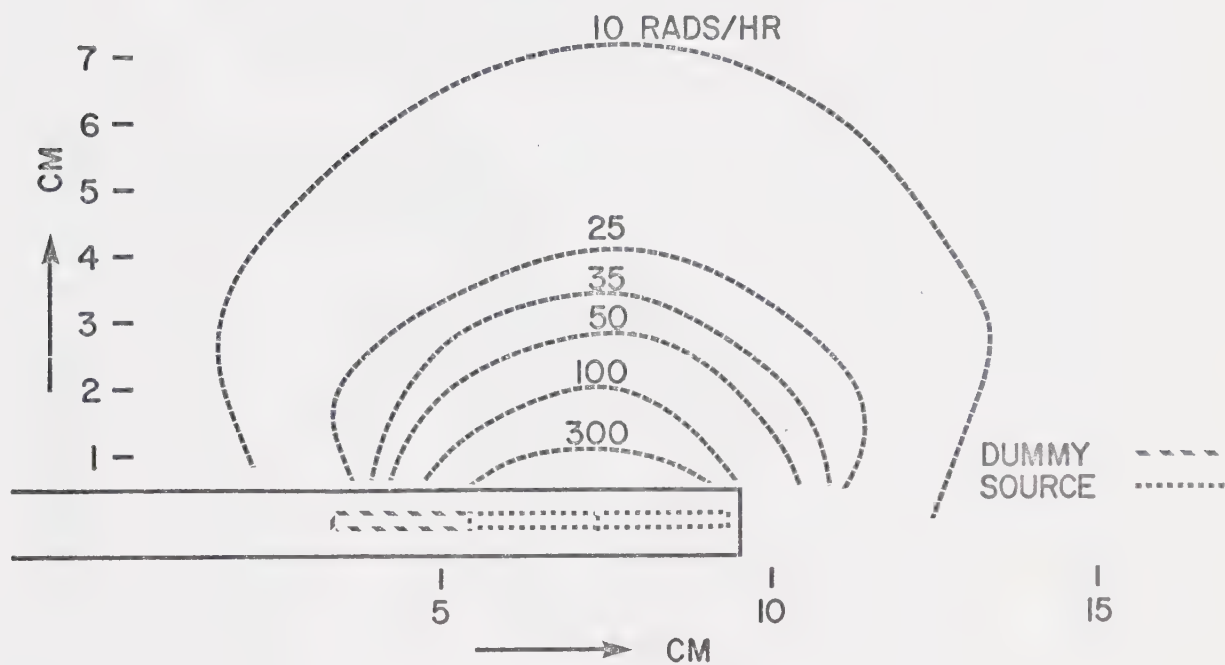
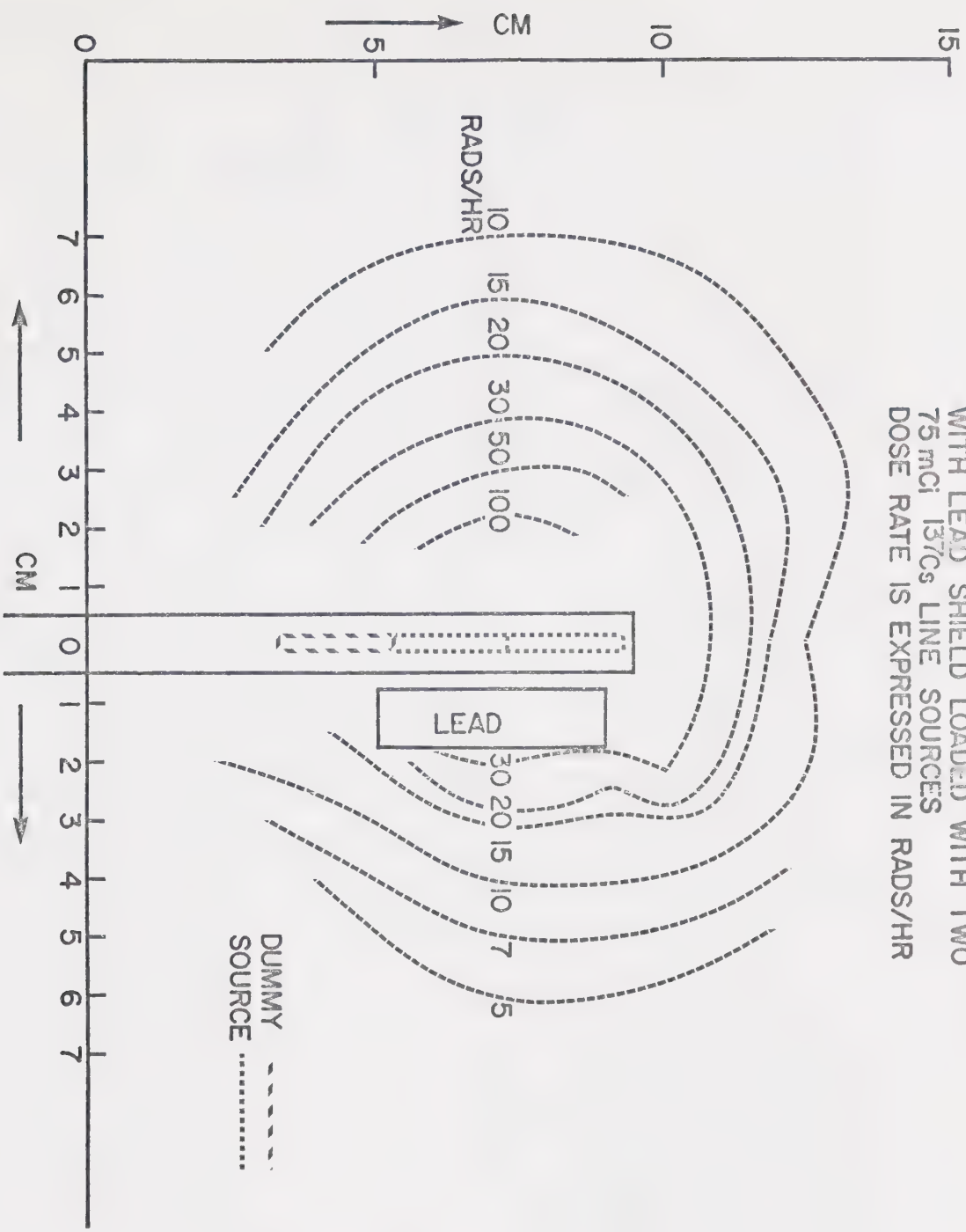


Fig. : 25
 ISODOSE CURVES FOR VAGINAL APPLICATOR
 WITH LEAD SHIELD LOADED WITH TWO
 75 mCi ^{137}Cs LINE SOURCES
 DOSE RATE IS EXPRESSED IN RADS/HR



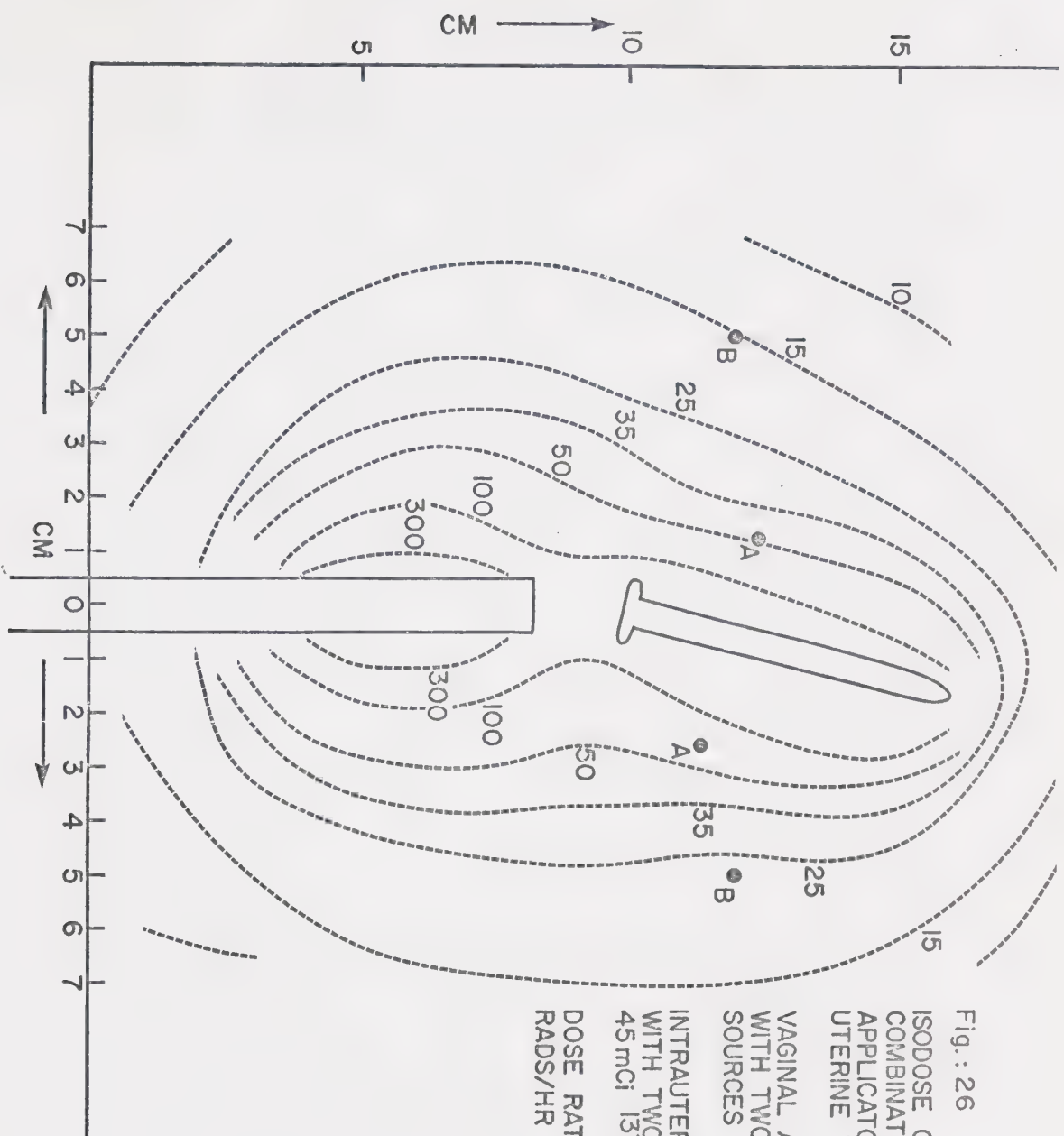


Fig.: 26
 ISODOSE CURVES FOR THE
 COMBINATION OF VAGINAL
 APPLICATOR AND INTRA-
 UTERINE TUBE
 VAGINAL APPLICATOR LOADED
 WITH TWO 75 mCi ¹³⁷CS LINE
 SOURCES
 INTRAUTERINE TUBE LOADED
 WITH TWO 30 mCi AND ONE
 45 mCi ¹³⁷CS LINE SOURCES
 DOSE RATE IS EXPRESSED IN
 RADS/HR

CHAPTER 5

CLINICAL IMPLICATIONS

5.1 Interstitial and Intracavitary Radiotherapy

Interstitial radiotherapy is a technique which consists of the insertion of radioactive sources into a tumour or into tissue in the immediate vicinity of a tumour. Interstitial sources are used widely for the treatment of intra-oral and superficial tumours.

Intracavitary radiotherapy is a technique by which the radioactive sources are introduced into the natural body cavities or hollow organs such as uterus, vagina, bladder or nose. The sources used are normally in the form of a line source each containing a substantial amount of radioactive material. An example of the use of intracavitary sources is in the treatment of carcinoma of uterine cervix.

Radium-226 sources have long been used in interstitial and intracavitary radiotherapy⁽³⁹⁻⁴⁶⁾. The very long half life of radium enables sources, once sealed, to be stored and used over many years without corrections for decay or need for replacement. ^{137}Cs , with a half life of 30 years, has recently been used as a substitute for radium⁽⁴⁷⁾. Its principal advantage is the reduced hazard associated with the rupture and leakage of sealed radium sources. In addition, its

characteristic energy of 0.661 MeV permits a smaller thickness of shield to be used compared to radium for the same effect. Such shielding is required both for personnel protection and manipulation of dose distribution within the patient.

Once the radioactive sources are introduced into the area or cavity under treatment, a radiographic examination of the position of the sources is done. This examination is important from the point of view of both clinical and physical studies. Clinically the radiographs ascertain that the sources are in the desired area for treatment. When the sources are inserted into tissue, their placement is often different from that planned. Hence the assessment of the total time of treatment may be significantly greater or less than that planned. The treatment time should thus be altered to correct for this difference in actual source position. The actual position of the sources and the area of treatment are determined from radiographs exposed at right angles to each other. Usually anteroposterior (AP) and lateral radiographs are used. These radiographs for a particular insertion are shown in figures 27 and 28.



Fig.: 27

Anteroposterior radiograph



Fig.: 28

Lateral radiograph

5.2 Point Source Approximation used in the Estimation of Dose Rate at the Points of Interest

The treatment of carcinoma of the cervix is done by intracavitary and external beam radiotherapy. For intracavitary treatment line sources are distributed in an intrauterine tube and a vaginal applicator and are inserted into the body cavities.

Since the dose distribution around these sources is not homogeneous but falls off from the sources outwards, it is desirable to choose some point or points at which the dose can be assessed and are of clinical interest. A point 2 cm lateral to the center of the uterine canal and 2 cm from the mucous membrane of the lateral fornix in the plane of the uterus, was selected clinically and is designated "Point A".⁽⁴⁵⁾ The dose at each of the two "points A" (left and right) is assessed. Although the dose is normally calculated for the points A, it is useful to know the rate of fall of dose beyond A. Thus, another point "Point B" is defined. It lies near the lateral pelvic wall 5 cm from the mid-plane and at the same level as point A. The total dose or the dose rate is then calculated at points A and B.

The point source approximation described here was used as a preliminary method to calculate the dose rate at different points. The active length of the line sources was divided into many small portions such that

each portion could be represented by a point source. The AP and lateral distances at points A and B from these point sources were measured directly from the respective radiographs.

As radium sources have long been utilized for treatment, the point source approximation was primarily used for radium sources. To use this approximation for radium substitutes such as ^{137}Cs , the source strength was modified in terms of milligram of radium equivalent (mg Ra eq). A radium equivalent is defined as the number of milligrams of ^{226}Ra in the form of a point source screened by 0.5 mm of platinum which gives the same exposure dose rate as the specified source at a distance of 25 cm in air. As the ^{137}Cs sources were contained in an intrauterine tube and a vaginal applicator of 1 mm and 2 mm thick steel sheath respectively, the source strengths were modified for the buildup factor and the attenuation through steel. The values of buildup factors were taken from the experimental curve (figure 16) for iron. These values are 1.06 and 1.10 for 1 mm and 2 mm thickness respectively. The attenuation factors for 1 mm and 2 mm of steel were calculated to be 0.945 and 0.890 respectively. The values of linear attenuation coefficient (μ) were obtained from Hubbell's data⁽³⁷⁾. Thus, the corrected source strength through the intrauterine tube was

1.06 × 0.945 times the source strength in mg Ra eq and through vaginal applicator this was 1.10 × 0.89 times the source strength. The AP and lateral distances were corrected for the magnification, if any, of the radiographic image. The magnification corrections were determined for both AP and lateral radiographs by placing rings of known diameter on both sides of the patient, and taking the ratio of the image diameter to the actual diameter of the rings. Once the corrected source strength, the AP and lateral distances and the magnifications were known at the point of interest, the dose rate from this point source was calculated by the formula:

$$\text{Dose rate (Rads/hour)} = \frac{SS \times 8.25 \times 0.955}{(M_{AP} \times \text{AP distance})^2 + (M_L \times \text{Lateral distance})^2} \quad (13)$$

where

SS is the corrected source strength in mg Ra eq.

8.25 is the dose rate in roentgens per hour at 1 cm from 1 mg of radium filtered through 0.5 mm of platinum.

0.955 is the conversion factor for roentgens into rads (the unit of absorbed dose) in tissue.

M_{AP} is the magnification of AP radiographic image.

M_L is the magnification of lateral radiographic image.

The sum of the dose rates from such point sources is the dose rate at the point of interest. The APL program for these calculations is given in Appendix A.

5.3 External Beam Shield used in Treatment with Teletherapy Units

Teletherapy or external beam therapy is used for treating many malignant diseases. Some of the common diseases where radiotherapy is preferred are:

Hodgkin's disease

Carcinoma of the mouth

Carcinoma of the uterine cervix

Carcinoma of the bladder

During the treatment of most of the diseases carefully shaped lead shields are used to provide maximum protection to such vital structures as the lungs, heart, liver, kidneys etc. The thickness of the lead shield is chosen such that the protected organ gets less than 5% of the exposure during treatment.

For the treatment of the carcinoma of the uterine cervix both intracavitary and external beam radiotherapy are commonly used. The dose delivered at the representative points A during treatment by the insertion of the cervix applicators is about 7000 rads.

This dose is normally delivered over a period of about 120 hours in two insertions. The dose at the points B cannot reach a tumour-lethal dose from the cervix applicators alone. Normally the dose delivered at the points B during treatment is about 2000 rads. The total dose at the points B is made up by using external beam therapy. The megavoltage teletherapy units are used to give a desired exposure at the points B, while protecting the area between the two points A. The area between the two points A is shielded by using a special lead shield in the teletherapy beam.

5.4 Usefulness of the Buildup Data for the Assessment of Shield Thickness

As discussed earlier in Section 5.3, a shielding material is sometimes required to protect the vital organs from the beam of the teletherapy units during treatment. The thickness of the shielding material required is normally calculated either by using the half value thickness for a particular material and energy of the radiation or by calculating directly from the formula:

$$I = I_0 e^{-\mu x} \quad (1)$$

where I , I_0 , μ and x have the same meaning as defined in Chapter 2.

Both these methods do not take into account any contribution due to the scattered radiation in the shielding material and are thus applicable only for narrow beam attenuation. For the treatment, in general, a beam of finite cross-section is employed, and the contribution due to scattered radiation should thus be accounted for in these calculations. It was seen in Chapter 4 that the scattered radiation contribution or the buildup factor was quite significant even at small thickness of an absorbing material. Thus, the values of the absorber thickness obtained by calculations of the narrow beam attenuation cannot be taken for a beam of finite cross-section. These values should be modified by using the value of the buildup factor for a particular shielding material as given in figures 15-21B or else the thickness of the absorbing material required to attenuate the beam to a desired level could be read directly from figures 15-21A of Chapter 4.

CHAPTER 6

CONCLUSIONS

6.1 Results and Discussion on Buildup Factors

The buildup factors for lead and iron as observed experimentally, for both ^{137}Cs and ^{60}Co radiations for a finite beam cross-section, were in good agreement with the theoretical values of buildup factors for a broad beam of a plane parallel source.

For water as an absorbing medium the buildup factors were found to be lower than the theoretical values. This was probably due to: (a) The limitations imposed by the possible experimental arrangements e.g. the dimensions of the polyethylene container and the restricted space between the sourcehead of the unit and the detector. Due to these limitations a fraction of the beam was not intercepted by the absorbing medium giving rise to lesser scattered radiation and hence to lower buildup factors. (b) The larger thickness of the absorbing material so that beam geometry was no longer comparable with the plane parallel source.

The effect of the detector positions behind the absorber, upon the buildup factor was as expected; the buildup factor should decrease with an increase in the distance of the detector from the absorber. The angle subtended at the detector by the irradiated absorber

becomes smaller with increasing distance from the absorber, so that the detector sees a smaller fraction of the scattered radiation.

For ^{137}Cs radiation and lead as an absorber, this effect with detector position could not be observed with the 14 cm diameter beam. This might be ascribed to the following reasons. One: that in this case the photoelectric effect is more dominant and the total scattered contribution is small. Two: "broad beam geometry" is attained at a smaller field size of the beam, and thus the variation in subtended angle at the detector with detector position is relatively small for the 14 cm diameter beam, and so produces negligible change in the scattered radiation detected.

6.2 Radiation Distribution Results and Discussion

The TLD cups used for mapping the radiation distribution around ^{137}Cs line sources were found to be useful and accurate. The dose rate at various points from a single line source was compared with the theoretical values. This comparison is given in table 2. The isodose curves for the individual sources could be superimposed to estimate the dose rate at any point of interest for any combination of sources. Further, these isodose curves could be modified for attenuation of any shielding material by using the appropriate measured attenuation curves.

Table 2

Comparison of experimental and theoretical values
for a single 21.5 mg Ra eq ^{137}Cs line source

Experimental points as defined by Young and Batho*		Young and Batho ⁽³⁸⁾ rads/hr	Experiment rads/hr	Quimby ⁽⁴⁸⁾ rads/hr	Point Source Approximation
x	y				
cm	cm				
0	2	42.47	43.5	41.31	41.25
0	3	21.23	22.35	18.60	18.69
0	4	11.21	10.43	10.68	10.58
1	2	34.21	33.0	33.32	33.95
1	3	17.32	18.52	16.90	16.94
1	4	9.69	9.5	9.86	9.99
2	3	13.21	13.75	12.73	13.17
3	2	13.17	14.10	12.26	13.41
3	4	6.60	6.20	6.57	6.85
4	2	7.79	7.50	7.80	8.68
Standard Deviation		5.39%		7.93%	9.44%

* y is the perpendicular distance of the point from the axis of the source.

x is the displacement of the perpendicular from the centre of the active length of the source.

REFERENCES

1. W.R. Dixon, Phys. Rev. 85, 498 (1952).
2. W.R. Dixon, Nucleonics 10, No.3, 42 (March 1952).
3. K.I. Ponnunni Kartha et al, Am. J. Roentgenology, radium therapy and nuclear medicine Vol. XCVI, No.1, 66 (1966).
4. U. Fano, L.V. Spencer and M.J. Berger in: Encyclopedia of Physics, S. Flügge (ed), Vol. XXXVIII/2, Berlin/Göttingen/Heidelberg: Springer (1959)pp. 674-684 and 668-669.
5. J.J. Fitzgerald, G.L. Brownell and F.J. Mahoney, Mathematical theory of radiation dosimetry, Gordon and Breach, Science Publishers Inc. (1967) pp. 237-252.
6. H. Goldstein and J.E. Wilkins Jr., U.S.A.E.C. report NYO-3075 Nuclear Development Associates Inc. (1954).
7. L.V. Spencer and U. Fano, J. Res. Natl. Bur. Std. 46, No. 6, 446 (1951).
8. G.H. Peebles, J. Appl. Phys. 24, No.10, 1272 (October 1953).
9. G.H. Peebles, J. Appl. Phys. 24, No.12, 1437 (December 1953).
10. D.J. Raso, Health Physics 5, 126 (1961).
11. M.J. Berger and D.J. Raso, Rad. Research 12, 30 (1960).
12. D.J. Raso, Nucl. Sci. Eng. 17, 411 (1963).
13. A.B. Chilton, Nucl. Sci. Eng. 24, 200 (1966).

14. W.R. Bruce and H.E. Johns, Brit. J. Radiol., Supp.#9 (1960).
15. Engineering compendium on radiation shielding, Vol.1, R.G. Jager (ed), pp.210-226 (1968), Springer-Verlag/Berlin/Heidelberg/New York.
16. A.B. Chilton, Nucleonics 23, No.8, 119 (1965).
17. Scintillation Spectrometry II, ed. R.L. Heath, U.S.A.E.C. report TID-4500 (1964).
18. J.T. Randall and M.H.F. Wilkins, Proc. Roy. Soc. (London) A184, 347 (1945).
19. G.F.J. Garlick in: Encyclopedia of Physics, S. Flügge (ed), Vol.XXVI/2, Springer/Berlin (1958), pp.1-128.
20. J.H. Schulman, Solid state and chemical radiation dosimetry in medicine and biology, I.A.E.A., Vienna, STI/PUB/138, p.3 (1967).
21. J.R. Cameron et al, Health Physics 10, 25 (1964).
22. C.J. Karzmark et al, Phys.Med. Biol. 9, 273 (1964).
23. N. Suntharalingam et al, Luminescence Dosimetry, U.S.A.E.C. report CONF-650637, 217 (1967).
24. W.R. Hendee, Health Physics 13, 1235 (1967), note.
25. P.R. Almond et al, Proc. of the second international conference on luminescence dosimetry, U.S.A.E.C. report CONF-680920, 410 (1968).
26. N. Suntharalingam et al, Phys. Med. Biol. 13, 97 (1968).
27. P.R. Almond et al, Phys. Med. Biol. 12, 389 (1967).
28. D.W. Zimmerman et al, Health Physics 12, 525 (1966).

29. M. Cohen, D.E.A. Jones and D. Greene (ed)
Brit. J. Radiol. Supp.#11, p.107 (1972).
30. Margarete Ehrlich, Photographic dosimetry of X- and
gamma rays, N.B.S. Handbook 57 (1954).
31. M.J. Berger and J. Doggett, J. of Res. Nat. Bureau
Std. 56, No.2, 89 (1956).
32. L.A. Beach et al, Phys. Rev. 92, 355 (1953).
33. F.S. Kirn et al, Radiology 63, 94 (1954).
34. G.R. White, Phys. Rev. 80, No.2, 154 (1950).
35. J.O. Elliott et al, Phys. Rev. 85, 1048 (1952).
36. C. Garrett and G.N. Whyte, Phys. Rev. 95, 889 (1954).
37. J.H. Hubbell, Photon cross sections, attenuation
coefficients and energy absorption coefficients
from 10 KeV to 100 GeV, U.S. Dept. of Commerce
NSRDS-NBS 29 (1969).
38. M.E.J. Young and H.F. Batho, Brit. J. Radiol. 37,
38, 689 (1964).
39. M.C. Tod and W.J. Meredith, Brit. J. Radiol. 11, 809
(1938).
40. M. Lederman and L.F. Lamerton, Brit. J. Radiol. 21,
11 (1948).
41. W.J. Meredith, Radiology 54, 386 (1950).
42. M.C. Tod and W.J. Meredith, Brit. J. Radiol. 26, 252
(1953).
43. F. Baracchi and S. Russo, Brit. J. Radiol. 33, 333
(1960).

44. J.A.C. Fleming et al, Clinical Radiology 14, 28
(1963).

45. Radium dosage - The Manchester System - W.J. Meredith
(ed), II edition, Baltimore, William and Wilkins
Co. (1967).

46. Thelmo Bates et al, Brit. J. Radiol. 41, 119 (1968).

47. A.F.C. Horsler et al, Brit. J. Radiol. 37, 385
(1964).

48. E. Quimby, Radiology 43, 572 (1944).


```

[13]  DR ← 0
[14]  '
      DATE:
      '
[15]  DR ← 0
[16]  '
      DOSERATES AT POINTS P1 THRU P'; 1 ← ρLAT
[17]  ''
[18]  + / ((ρDR)ρSS) × DR ← 8.25 × 0.955 ÷ ((MAGL × LAT) * 2) + (MAGA × AP) * 2
[19]  → 0
[20]  '
      ***COORDINATES NOT IN PAIRS.  TRY AGAIN***
      '
[21]  → 1
[22]  '
      ***NUMBER SOURCES ≠ NUMBER COORDINATES.  TRY AGAIN***
      '
[23]  → 11
      ∇

```


B30034